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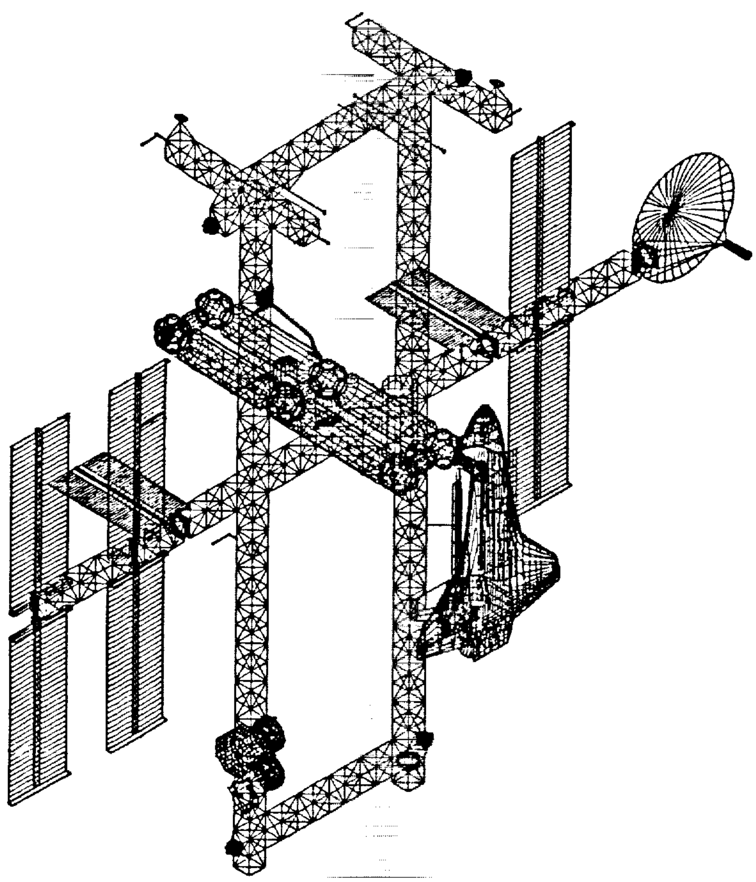
SESAC Task Force
on Scientific Uses of Space Station

SPACE STATION SUMMER STUDY REPORT



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FOREWORD

This report presents the results of the second (1985) summer study of NASA's Space and Earth Science Advisory Committee (SESAC) Task Force on the Scientific Uses of Space Station (TFSUSS). As in the first (1984) summer study, the membership of the TFSUSS was augmented by a number of invited participants from the scientific community and NASA. As previously, a significant number of international observers were present and took active part in the deliberations of the study teams. The TFSUSS greatly appreciates the efforts of its summer study participants and acknowledges the many important contributions made by them to this report.

In the year since the first summer study report, many developments have taken place in NASA's Space Station Program. The organization of the NASA Headquarters Office of Space Station came to full fruition, while the Level B Office at Johnson Space Center made important steps towards definition of the Space Station by issuing a comprehensive system definition as part of an industrial RFP document. Initiation of the important first phase of Space Station definition was made in early 1985 with the award of work package study contracts by Level C Space Station study groups at Goddard Space Flight Center, Johnson Space Center, Lewis Research Center, and Marshall Space Flight Center. Perhaps more importantly, NASA's Office of Space Science and Applications took definitive actions with respect to incorporating the new Space Station facilities into its long-range plans by providing the Space Station planners with a balanced evaluation of potential missions for the early- and mid-1990's.

TFSUSS itself has been intimately involved in these and many other activities. During the year between the summer studies, three important meetings of the advisory committee were held at different NASA field centers. Each of these resulted in recommendations to NASA with respect to the Space Station Program and the role and implications of Space Station to the United States and international plans for research activities in space.

The material contained in this report was written by the summer study participants and brought to its final form through a smaller group of editors. It is appropriate for us to express our thanks for the strong support provided by many different individuals. In particular, Dr. Burton I. Edelson, the Associate Administrator for Space Science and Applications, and Mr. Phillip E. Culbertson, the Associate Administrator for Space Station, have taken an active part in the activities of the Task Force, and their presence and interest have been most welcome. Other individuals who can be singled out for their counsel and advice include Mr. Richard S. Sade, Executive Secretary for the TFSUSS and Deputy Associate Administrator (Programs) in the Office of Space Science and Applications, Dr. William P. Raney, Director, Utilization and Performance Requirements Division in the Office of Space Station, and Mr. Carl Shelley, Manager of the Space Station Customer Integration Office at Johnson Space Center.

We also wish to extend our thanks and appreciation to Ms. Lee Ann Adams, Ms. Kathy Avery, Ms. Sharon Hughes, and Ms. Janet Strahm for their dedicated efforts in preparing for, caring for, and cleaning up after the summer study. As with the previous summer study, nothing would have been possible without the guiding organizational hand of Dr. William C. Wells.

Finally, we note that the material presented here was written prior to the Challenger accident. The members of TFSUSS wish to express their collective sorrow for this loss and feel it appropriate to dedicate this report to the memory of the seven individuals who died in this accident.

Peter M. Banks, Task Force Chairman

David C. Black, Summer Study Report Co-Editor

Hugh S. Hudson, Summer Study Report Co-Editor

February 28, 1986

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1.0 INTRODUCTION

1.1 HISTORY OF THE TASK FORCE ON SCIENTIFIC USES OF SPACE STATION

The SESAC Task Force was established as an ad hoc advisory committee within the NASA Advisory Council system in March 1984, with membership drawn from the major scientific disciplines represented within NASA's Office of Space Science and Applications. The charter of the Task Force provides for the participation of the group in a wide range of activities associated with NASA's development of the Space Station facilities. Specific charges to the Task Force include:

(1) To assist NASA in planning for the scientific utility of the Space Station,

(2) To assist NASA in understanding the relationship between the new Space Station capabilities and the existing space science and applications research program,

(3) To periodically update scientific requirements on Space Station hardware and operations,

(4) To act as a focal point for broad scientific community input to Space Station activities, and

(5) To interact as needed with contractors during the definition phase of Space Station development.

To discharge its responsibilities, the Task Force conducts quarterly public meetings. To acquaint the Task Force members with the broad spectrum of activities associated with and pertaining to the Space Station project, these meetings have been held at the various NASA field centers participating in Space Station work. An announcement of these meetings including an agenda is published in the Federal Register. Formal minutes of the proceedings are written and made a part of the record of the activities of the Task Force.

The essential products of the Task Force's work are information, advice, and recommendations. The rapidity with which initial plans for Space Station developed within NASA isolated the Space Station planners and engineers from the science community. This was true in two ways. First, the scientific user community did not understand what might best be done with the new, manned and unmanned facilities. Second, the Space Station planners did not appreciate fully the possibility of using modern telecommunications technology to eliminate the "remote outpost" character of research activities in space. The Task Force, through its meetings and general availability, has provided NASA with a critical sounding board for securing the opinions and advice from persons who have direct knowledge of the goals and practice of scientific research in space.

Many of the more important impacts of the Task Force come about through individual or small group encounters with Space Station managers and engineers. These happen at both the formal Task Force meetings and at smaller gatherings. Through electronic mail, the Task Force has been able to respond rapidly to requests for evaluating many different aspects of Space Station planning. The direct and electronic mail participation of the TFSUSS in the two Space Station Reference Update Reviews (July and October 1985), for example, gave information to the Level B planners that affected several areas of Space Station configuration used by contractors in their Phase B studies.

More formal advice and recommendations to NASA resulting from its regular meetings have been given through summary letters from the Task Force Chairman to the Associate Administrators for Space Science and Applications and for Space Station. In many cases, these letters focus attention on long-term, institutional issues rather than immediate issues involving Space Station designs.

In addition to its quarterly meetings, the Task Force has also sponsored two summer studies. The first was held during August 1984 at Stanford University with participants drawn from the TFSUSS, the U.S. scientific community, and NASA. In addition, a number of international observers were invited and took active roles in the summer study activities. A record of the results of the first summer study has been given in a TFSUSS report, "Space Station Summer Study Report", dated March 21, 1984. The second TFSUSS summer study, held August 19-23, 1985 at Stanford University, is the subject of the present report.

1.2 TFSUSS CONCERNS: 1984-1985

As a backdrop to the 1985 summer study, it is important to review the major preoccupations of the Task Force during the period following the 1984 summer study. These include the following:

(1) **OSSA Missions for Space Station**. The development of a realistic OSSA mission set for Space Station is important both for communicating system resource and operation requirements to the Space Station Program, and for developing plans for implementing a consistent national program of research in space.

(2) **Science Operations Studies**. Little attention has been given to understanding the organization and implementation of scientific activities in the manned core facility. Experience gained from Spacelab and other attached payload programs using the Space Transportation System has shown that considerable thought must be given to a wide variety of topics related to research operations. These topics include crew composition and size; crew training; task simulation; communications with ground-based investigator group; the need to support a capability for the conduct of "adaptive" science experiments; and on-orbit instrument storage, maintenance, calibration, testing, and set-up facilities.

(3) **Communications and Information Systems Requirements**. The TFSUSS is convinced that important improvements could be made in the conduct of research in space by creating close links between the space-based laboratories and facilities, the on-orbit crew, and geographically dispersed ground-based investigator groups. A new word, "telescience," was coined by the Task Force to express the concept of applying modern telecommunications technology and capabilities to the pursuit of scientific research in remote manned laboratories.

(4) **Assembly, Service, and Repair**. The Task Force supports the concept of on-orbit service for space instruments and satellite systems. Each of the scientific teams sees important ways to use such resources to the benefit of its particular style of research activity. However, a specific concern was expressed about the allocation of crew time. Unexpected repair activities could conflict with the conduct of a stable scientific schedule. The ways such conflicts can be

minimized and handled on a regular basis must be studied as part of the overall plan of optimal crew use.

(5) **The Acceleration Environment of the Space Station Laboratories**. There is a diversity of scientific activities associated with life science, materials science, and other disciplines which require an environment having very low acceleration levels for periods as long as several weeks. Investigation of experiment requirements by TFSUSS showed that accelerations as low as 10^{-6} g would be needed for some important experiments, and that displacement of the research facilities away from the center of gravity of the Space Station could violate this requirement. After discussion, the Space Station Project Office introduced a new Space Station configuration for contractor study that greatly improved the acceleration environment in the laboratory modules.

(6) **Space Station Platforms**. Free-flying platforms are an important part of the Space Station concept. There are requirements for both single facility and multi-instrument platforms. The Task Force has supported the development of a new class of modular platforms which can meet the expected range of needs in a flexible way. There is also a need for subplatforms that can be used for relatively limited on-orbit duration. While not part of the Space Station these smaller systems complement the modular station platforms.

(7) **Extended Duration Orbiter**. Experience in the effective use of human resources for scientific activities in space is important to the development of Space Station. Spacelab flights are an effective way of gaining such experience. However, the current limit of 5 to 7 "effective" days on orbit with Spacelab has led to the development of a highly mechanized, time-constrained scientific environment that is substantially different from that of the "adaptive science" atmosphere of successful terrestrial laboratories. Recognizing this, and seeing the intrinsic value of obtaining greater on-orbit time for conducting scientific research, the Task Force has strongly supported the development of an extended duration capability for the Shuttle, which would allow experiment periods as long as 14 to 16 days.

(8) **Space Station Configuration**. The Task Force has been involved in a number of discussions related to the design of the Space Station facilities. These topics

include module size, attached payload facilities, on-orbit installation of experiment facilities, stability and pointing capabilities for outward looking instruments, hatch sizes, cabin atmospheric pressure and composition, electrical power, and a quick sample return capability. Many of these decisions carry important consequences for later scientific activities, and it is for this reason that the Task Force has expressed its opinions and recommendations directly to the Space Station Project Office.

(9) **International Participation**. The international character of the Space Station has been a central theme of NASA. Extensive hardware commitments are being made, and there is a realization that development of Space Station is a truly international undertaking. Representatives from the European Space Agency and its constitutive countries, as well as from Canada, Japan, and India, have participated closely in the activities of the TFSUSS. There is an increasing appreciation of the need for defining the role of an international scientific program as an integral part of the general Space Station agreements. The Task Force strongly supports the concept of a unified scientific program that incorporates the talents of the international scientific community under a philosophy of sharing the available facilities.

1.3 THE 1985 SPACE STATION SUMMER STUDY

The 1984 summer study occurred only 4 months after the formation and first organizational meeting of the TFSUSS. At that time, the NASA Space Station planners, charged with the task of getting the Phase B contractor studies underway, had had little contact with the scientific plans of the Office of Space Science and Applications (OSSA) and the national scientific community. In this situation, the Task Force was called upon to assist both NASA Headquarters and the Field Centers in a variety of ways. Long-term scientific utilization plans setting forth basic system resource requirements were needed. This was the responsibility of OSSA, and the Task Force spent considerable time at the first summer study and thereafter assisting in the development of a formal requirements document. More immediate concerns about specific aspects of the system plans for Space Station were also brought to TFSUSS for its evaluation and advice. As a consequence, the 1984 summer study report was our first attempt to call attention to a broad range of potential problems.

By the summer of 1985, many of the issues confronting NASA and the Task Force had been explored to the point where the TFSUSS could focus its attention on a smaller menu of topics than had been the case the previous year. While the 1984 summer study had been organized to secure information about the plans and facility needs of various scientific disciplines with respect to Space Station, the 1985 study was able to take a longer range view of the Space Station within the context of research in space. In particular, reflection over the events of the previous year led to the conclusion that serious thought had to be given to the ways in which the resources and capabilities of a manned Space Station could be used to the best scientific advantage.

Thus, it was decided that the 1985 summer study would have two overlapping organizational structures. As in 1984, scientific discipline-oriented teams were created to review and comment upon discipline related topics as they related to proposed uses of Space Station. The list of discipline teams and their team leaders follows:

Astronomy and Astrophysics -- Dr. Hugh S. Hudson
Solar System Exploration -- Prof. James L. Elliot
Solar-Terrestrial Processes -- Dr. C. Richard Chappell
Earth Observations -- Prof. David A. Landgrebe
Life Sciences -- Dr. Richard S. Young
Microgravity Sciences and Applications -- Dr. John Carruthers
Physics and Chemistry in Space -- Dr. Joseph K. Reynolds

In addition, and perhaps more importantly for the summer study, pan-discipline teams were organized in an attempt to give cross-discipline evaluation on four topics thought by the Task Force to be of singular importance to the success of the Space Station as a scientific research facility. These teams were composed of representatives from each of the discipline teams and, over the course of the week's study, received much of the time available for formal presentations and team discussion.

The pan-discipline teams, their team leaders, and their areas of interest are:

Space Station Configuration (Dr. Owen K. Garriott) -- Impacts of various architectural and system design issues with respect to the broad needs of the science user community,

Space Station Platforms (Dr. David C. Black) -- Needs and desires of the space research community with respect to scientific experiment accommodations and resources separate from the manned core station,

Science Operations (Dr. Byron K. Lichtenberg) -- Development of an understanding of the way scientific research can be organized and implemented using the unique facilities of the manned core facilities, and

Communications and Information Systems (Dr. Michael J. Wiskerchen) -- Concepts of Space Station telecommunications suitable for the present and future needs of scientific users.

Six major objectives given to the 1985 summer study were:

(1) Review current Space Station definition plans from the perspective of the scientific user community,

(2) Review OSSA plans for utilizing the Space Station,

(3) Review and continue to develop science user requirements for Space Station facilities,

(4) Explore issues related to international participation and collaboration in Space Station science programs,

(5) Examine plans for utilization of a Space Station constrained in various types of resources including supporting facilities, crew size, and financial support for science programs, and

6) Provide NASA with advice concerning the evolution of Space Station from its Initial Operational Capability (IOC) configuration.

In addition to these, two other topics presented for general discussion by the participants were:

(7) Examine issues related to the rapid execution of small-scale, innovative scientific experiments, and

(8) Evaluate the potential scientific uses of platforms located in geosynchronous orbit.

Over the course of the 5 days of the study, these topics were subject to considerable discussion and debate by the participants. The results are given in the following two chapters. Chapter 2 presents the conclusions and recommendations of the discipline teams, while Chapter 3 gives results from the pan-discipline groups.

The ordering of daily activities of the summer study can be seen in the final agenda given in Appendix B. In keeping with the informal nature of the proceedings, plenary presentations were restricted to essential topics of general interest. However, several group discussion periods were scheduled during the week, including one for the final wrap-up presentations of the team leaders.

2.0 REPORTS FROM THE DISCIPLINE TEAMS

A permanently manned Space Station will propel space research into new territory. New scientific disciplines will appear in space, and "traditional" ones will evolve. While the introduction of the Space Shuttle may have had a negative impact on many branches of space research, the Space Station will mark the beginning of a revolutionary change that ultimately will benefit all disciplines.

The development of the Space Station appears to provide fewer technology challenges to NASA and its international partners than did the Space Shuttle. This is good news for science and applications, because it means that we should be able to preserve greater continuity in the development and exploitation of research opportunities. Indeed, we must use the Space Shuttle and Spacelab to gain valuable experience for use of future manned laboratories in space, and in improving our capability for telescience.

The following sections give a discipline-by-discipline analysis of the effect of the Space Station on science and applications. This analysis has proceeded in parallel with the design studies for the Space Station. The Task Force commends NASA on its support for utilization studies concurrent with the actual Space Station hardware design. As with the first summer study, the results reported here were generated amidst the hubbub and confusion of the design studies themselves. Thus, the results may appear patchy and incomplete; some issues that appeared important then may no longer be significant. At the 1985 summer study, there was an atmosphere of accomplishment in many areas, since participants had seen the positive results of many of their earlier suggestions regarding the Space Station design.

2.1 ASTRONOMY AND ASTROPHYSICS

The development of the Space Station system offers real opportunities for accelerating the pace of research in astronomy and astrophysics. These disciplines have benefited greatly from access to space in the past, and a new generation of space observatories is now half-completed. The Space Station will immediately provide the resources needed for the servicing of these observatories and other free-flying instruments, a natural extension of the capabilities already demonstrated several times by the Shuttle. We look forward also to fundamentally new observational developments made possible in the future by the greater ease of access to space.

In the following three items, we summarize the conclusions of discussions at the 1985 summer study of the Task Force. These overlap in large measure with the conclusions from the 1984 summer study.

1. **The Space Station shall provide for the servicing/upgrading of modular free-flying platforms for astrophysics.**

Servicing the great space observatories, including the pre-IOC Hubble Space Telescope (HST) and Gamma-Ray Observatory (GRO), as well as the Advanced X-ray Astrophysics Facility (AXAF) and Space Infrared Telescope Facility (SIRTF), is a major rationale for the association of astrophysical research with the Space Station. The Space Station is required to provide the servicing, regular maintenance, repair, and instrument replacement/updating/reconfiguration necessary to allow at least 15 years of overlapping and simultaneous use of the great space observatories. In addition, the Space Station Program should be charged to interact with the AXAF and SIRTF projects to provide for Station-compatible interfaces for modular support units in order to ensure their operation as Space Station platform payloads.

2. **The Space Station should provide basing and servicing for small attached and free-flying instruments for astrophysics.**

The Space Station will provide an ideal logistics base for accommodating co-orbiting subplatforms (e.g. Spartans), as well as small attached payloads. The Space Station attached payloads include individual instruments in cosmic-ray physics, gamma-ray astronomy, X-ray astronomy, ultraviolet-optical-infrared astronomy, and radio astronomy, some of which have been developed for Spacelab. Such smaller programs offer frequent opportunities for experimental investigations, filling a vital role in student training, instrument development, and innovative science. The essential characteristic of these opportunities is their flexibility and independence, leading to a quick return of valuable data in the shortest possible time following the appearance of the concept.

The Space Shuttle presently supports many minimum-interface programs for small-scale science: Get Away Special (GAS) cans, Hitchhikers, Long Duration Exposure Facility (LDEF), etc., as well as the Spartan free-flyers. This capability should continue and increase in importance as we gain experience with Shuttle operations. It is most important that we make a smooth transition in programs of this type between the Shuttle and the Space Station. Thus, the Space Station should be designed to incorporate many programs of this type. This is one of the means by which the Space Station can aid us in responding to Freeman Dyson's slogan, "quick is beautiful," but we emphasize that the key to this concept is quickness, rather than smallness.

3. The Space Station should provide accommodation for the assembly, operation, and deployment of new large-scale facilities.

The manned base provides a unique capability for a number of scientific objectives in astrophysics; these include major attached observatories for solar physics and cosmic-ray physics in which the crew will be essential in facilitating observations and carrying out on-orbit servicing and for which the Space Station environment is suitable. The Advanced Solar Observatory (ASO) and the Particle Astrophysics Magnet Facility (Astromag) are typical examples of such attached facilities. We also look forward to the development of large free-flying observatories such as the Large Deployable Reflector (LDR), which can be assembled, tested, calibrated, and then released from the Space Station to fly into a more suitable orbit.

Such fields as gamma ray astronomy and cosmic ray physics are characterized by low event counting rates. To accumulate many events, therefore, requires large areas, large solid angles, and long times of observation. The Space Station will provide a unique ability to support these large instruments, which in general do not have demanding environmental requirements. Their observations are linked very closely with elementary particle physics emerging from the new ground-based particle accelerators, possibly providing crucial insight into the nature of the early universe and cosmology.

As the Space Station infrastructure and usage develop, it will be important to monitor and protect the observing environment for ultraviolet-optical-infrared wavelengths. Many disciplines will wish to make sensitive remote-sensing observations, and these will require control of contamination in terms of gases and debris in the Space Station vicinity. In addition, there will be broadly shared desires for unrestricted fields of view for instruments, and pointing control systems to aim them at a variety of targets. We urge that the design of the Space Station lay the groundwork for its future expansion in such a way that the inevitable growth and reconfiguration do not reduce its utility for astrophysics.

Astrophysics instrumentation will benefit from the development of the tools of telescience, specifically from nearly unrestricted access to real-time networking for data and command links between the investigators (at their home institutions, by preference) with the instrumentation, the Space Station facilities, and the crew. We expect that the volume of data will increase with time, approaching downlink data rates of 100 Mbps; uplink video will also be needed.

2.2 SOLAR SYSTEM EXPLORATION

The plan for solar system exploration and planetary science, developed by the Solar System Exploration Committee and reviewed by relevant committees of the Space Science Board, has the following goals:

- Determining the origin, evolution, and present state of the solar system,
- Understanding the Earth through comparative planetary studies,
- Understanding the relationship between the physical and chemical evolution of the solar system and the origin of life, and
- Survey of the resources available from near-Earth space.

The data needed to pursue these goals is obtained in four ways: (1) spacecraft missions to the planets and other solar system bodies; (2) laboratory experiments and simulations of processes that occur throughout the solar system; (3) observations of solar system bodies and other stars with Earth-based and Earth-orbiting telescopes that are equipped with a variety of spectroscopic and imaging instruments; and (4) analysis of extraterrestrial materials, such as meteorites and interplanetary dust. For each of these data channels, the Space Station offers exciting opportunities for new research. Below we discuss some of these opportunities and some considerations involved with their implementation on the Space Station.

Spacecraft Missions

The present solar system exploration program was configured before the national decision for a permament Space Station. This previous program was designed to use small, economical spacecraft that would allow frequent missions to the planets -- each growing from the experience of the previous ones.

The Space Station will allow assembly of larger, but not necessarily more expensive, spacecraft missions. Some of these experiments are improved versions of past experience, but with far greater science return simply because of the opportunity to make synoptic observations of the planets. For example, our knowledge of Venus has been obtained from separate entry vehicles to probe the Venusian atmosphere at different places and different times. The one exception was the Pioneer Venus mission which had four simultaneous entry probes. Jupiter and Saturn, however, have many more weather events than do the Earth or Venus. The dynamics of these planets' atmospheres is not yet understood. The "small" atmospheric features on Jupiter are larger than the largest atmospheric systems on Earth. Multiprobe missions, some equipped with many very simple probes, could give a much better picture of weather on Jupiter and Saturn.

One of the cornerstones of ESA's Horizon 2000 program is the Comet Nucleus Sample Return Mission. This mission has been the subject of a study to assess the requirements for a Space Station staging capability. The study assumes that the Space Station will be required to assist during both launch and retrieval phases of the mission. Preliminary results are encouraging, and a new, more detailed study phase, within the framework of ESA's Columbus Preparatory Program, is about to begin. This mission has also been the subject of talks with a view to a joint ESA-NASA undertaking.

Cost is always an important factor and an "erector set" approach to a wide variety of planetary missions is a way to reduce the long-term costs of the program. It is essential that the IOC design of the Space Station take proper account of these needs for future planetary exploration. These opportunities are exciting and should not be compromised.

Laboratory Experiments

A major opportunity afforded by the Space Station lies in the area of laboratory simulation of planetary processes and study of the basic behavior of materials under conditions that can be controlled to match those expected for a range of planetary environments. Examples of processes that have been simulated experimentally are impact cratering, volcanic eruptions, erosion and deposition of windblown sediments, atmospheric chemistry, and planetesimal formation. Many of these processes are expected to be sensitive to gravity and are occurring under low-gravity conditions, since all solid bodies in the solar system have surface gravities less than that of the Earth. The Space Station will permit extended studies of processes in a low acceleration environment and thus will allow an investigator to observe fundamental phenomena in new ways. For example, in a space environment it would be possible to keep dust suspended in vacuum for long intervals of time, allowing detailed study of dust-gas and dust-dust interactions. Both of these interactions are thought to have been crucial to formation of bodies in the early solar system. Another example is the study of the dynamics of particle interactions, a topic central to our understanding of the behavior of rings and the formation of planets from the solar nebula. The Space Station will also allow investigation of the behavior of planetary materials under high temperature conditions using "containerless" furnace technology, which will advance our understanding of long-standing issues in experimental petrology.

At the summer study, our discussions of laboratory experiments were concerned with the possibility of conducting experiments of interest to our field with laboratory facilities shared with other disciplines. The Space Station will be built and will function under severe mass, power, volume, and cost constraints. In many cases, it makes little sense for each of the scientific disciplines to pursue development of similar facilities. Rather, emphasis should be placed on developing, where appropriate, general-purpose laboratory facilities that can be used by people with different scientific interests, but similar equipment needs. There is also, of course, a danger in trying to develop facilities that will please everyone, and in the end be useful for no one. A balance must be struck. An emphasis should be placed now on the identification of facilities that can productively be used by more than one discipline.

Planetary Observations from Telescopes on the Space Station

Although the spectacular results from planetary missions have occupied the spotlight recently, Earth-based observations continue to produce important new advances in planetary science -- as examples we can point to the results of stellar occultations of planetary rings, spectroscopic observations of Io and its plasma cloud, and the wealth of new information about comets that has been obtained by many observational techniques. We expect the impact of remote observations of the system to dramatically increase as the development of new instrumentation is flourishing with advances in solid state detectors, and the prospect of Earth-orbital observatories will remove the degradation of data caused by the Earth's atmosphere.

The first major opportunity for planetary observations from near-Earth orbit will be provided by the HST. Planetary scientists are eagerly awaiting the launch and commissioning of this powerful observatory, but, looking to the future, they have recognized that some important needs for near-Earth planetary observations cannot be met with the HST. These are (1) observations within 45 degrees of the Sun, which all but precludes observations of Venus and comets near perhelion, and does preclude observations of Mercury, and (2) extensive synoptic observations of the major planets (there's just not enough time on this telescope, which must serve all of astronomy).

The perceived shortcomings of the HST for planetary astronomy can be overcome by telescopes and their associated instrumentation, which are attached payloads to the Space Station. Our first telescopic package, under serious consideration for IOC, is an astrometric telescope that would be used to search for planetary systems associated with stars other than the Sun. This project was described in last year's report. At this summer study, our main concern for this project is that the design of the Space Station be compatible with the inclusion of the astrometric telescope at IOC. It needs freedom of viewing and pointing in order to reach targets in any part of the sky. Also, the contamination of the near Space Station environment should not be so severe that it would cause the optics and other components of the system to deteriorate too rapidly.

Analysis of Extraterrestrial Materials

Studies of meteorites and interplanetary dust particles collected in the upper atmosphere have contributed fundamental information to all of the major goals of planetary exploration. The importance attached to sample return has been amply documented in many places, including the Complex Report on Primitive Bodies and numerous studies of comet, asteroid, and planetary sample return missions.

The Space Station offers the opportunity to open up a new chapter in laboratory studies of extraterrestrial materials. An appropriately designed dust collector facility will make it possible to determine the orbital elements of individual micrometeorites whose impact debris can then be returned to Earth for detailed laboratory investigations. The orbital information will make it possible to separately identify particles from comets, general interplanetary dust, and true interstellar materials. Because many particles will be studied, the range of properties characteristic of comets as a whole will be obtained -- something that can never be achieved by a sample return mission to one comet.

Studies of interplanetary dust collected in the stratosphere have demonstrated that the dust is a unique and important form of extraterrestrial material. Many of the particles are enriched in deuterium and show infrared absorption features similar to those found in protostars. They thus consist of primitive material that may well date back to the giant molecular cloud phase of solar system evolution.

The ability to determine elemental and isotopic compositions of impacting micrometeorites has been demonstrated in laboratory simulation experiments and, most recently, in studies of impacts found in the thermal blanket returned to Earth from the Solar Maximum Mission (SMM). Fragments of some SMM particles also appear to be relatively unaltered when viewed in thin section by high resolution electron microscopy, making the study of properly collected impact debris of interest to exobiologists.

Several experimental approaches to determining the orbital parameters of micrometeorites have been shown to be feasible and, indeed, some have already flown in space. Although a combined capture cell and orbital determination instrument has never been constructed, there appear to be no fundamental reasons why this cannot be done. However, developmental work and some flight testing will be necessary in the period prior to IOC.

The Space Station is a logical place for a dust collection and orbital determination facility. Because of the low flux of micrometeoroids, particularly those associated with meteor showers (and hence, known comets), large area detectors are required. Power is also required for the orbital trajectory measurements. Specific capture cell modules that have been identified as containing impacts with interesting trajectories need to be periodically removed and returned to Earth where they can be studied by a sophisticated array of microanalytic techniques. All of these requirements are best met in a facility associated with the Space Station.

Manmade orbital debris is now a recognized component of the particulate matter in near-Earth orbit. Indeed, most of the impacts found in the returned SMM materials are produced by such debris, not by cosmic dust. The concentration of orbital debris is certain to grow with time, and the dust collection and orbital determination facility will also contribute fundamental information on this problem.

2.3 SOLAR-TERRESTRIAL PROCESSES

Beginning with the Skylab mission of the early 1970's and continuing with the development of the Space Shuttle and Spacelab, the capabilities of manned space-flight have become increasingly available to the space science community. These capabilities have been recognized as being of fundamental importance to the community of scientists who study the Sun-Earth-space system. From the initial superb measurements of the Sun using the Apollo Telescope Mount on Skylab to the solar output, active space plasma physics, and atmospheric observations of Spacelab 1, to the atmospheric and auroral observations of Spacelab 3, to the active space plasma and solar observations of Spacelab 2, scientists in the solar-terrestrial processes discipline have taken advantage of the manned spaceflight capabilities and have laid plans for many of their future discipline activities with these capabilities in mind. The Space Station will bring an even further enhancement of the manned spaceflight opportunities for solar-terrestrial research, and it is at these new opportunities that the solar-terrestrial processes team has looked during both summer studies at Stanford University.

The first summer study discussed the potential role of the Space Station in conducting research in solar-terrestrial physics and found the opportunities to be very attractive. Based on the work of several study groups during the late 1970's and early 1980's [1-3], a strong set of science objectives exists in solar, magnetospheric, and atmospheric physics that could be accomplished through a coordinated set of measurements from low-Earth orbit. It was found that these measurements would be very nicely facilitated by the Space Station and could be made using an instrument set that has evolved from Spacelab flights in the 1980's and early 1990's. During the past year, the early conceptual ideas about the configuration of the Space Station have begun to crystallize and the specific programmatics of the instrument development for solar-terrestrial physics have become more clear.

The solar-terrestrial processes discipline encompasses the study of the entire Sun-Earth system including the detailed study of solar processes, the relationship between changes at the Sun and resulting changes in the Earth's magnetosphere and atmosphere, and the detailed physics of the Earth's magnetosphere-ionosphere-atmosphere system. Under this umbrella of objectives, one will find the goals of the Advanced Solar Observatory and Solar Terrestrial Observatory Programs as well as an overlapping interface with the Earth Observing System Program. The first two of these programs should be considered under the scientific banner of Sun-Earth observations and can be readily accommodated by the technical capability currently envisioned for the Space Station.

The study of the Sun, magnetosphere, and atmosphere will require measurements from the manned core, as well as from platforms. In particular, manned interactive

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[1] Solar-Terrestrial Observatory, Final Report of the Science Study Group, Dr. R. C. Canfield, Chairman, October 1981.

[2] Advanced Solar Observatory, Final Report of the Science Study Group, Dr. A. B. C. Walker, Chairman, February 1984.

[3] Earth Observing System, Science and Mission Requirements Working Group Report, August 1984.

observations of the Sun and active experiments highlight the importance of the attached payloads on the manned base with its observation station in the modules and an effective communications and data link to the ground that enables the onboard and ground-based scientists to interact. A system of this type will make possible the coordinated study of "target of opportunity" events in the Sun-Earth system such as solar flares and magnetic storms. The effective handling of data and communications with the telescience philosophy as a guiding strategy will facilitate major advances in our understanding of the coupling of solar-terrestrial processes.

This section also discusses plasma physics in space, a new field to be distinguished from space plasma physics, and solar-terrestrial observations from geosynchronous orbit. Both topics are motivated by new capabilities offered by Space Station.

Recommendations

The Solar-Terrestrial Processes Team has a very positive feeling about the approach taken thus far by the Space Station Program. It is clear to us that there is a responsiveness to the scientific user community; this responsiveness is a primary element of the overall management philosophy. Also, the idea of management by exception is indicative of a trusting approach by the Space Station with the user communities. We consider these general directions to be positive and are appreciative of the approach that has been taken.

It is clear that manned interaction is of fundamental importance and value to Sun-Earth studies from the Space Station. Examples such as the solar observing that we have seen on Spacelab 2 and the active experimentation done on Spacelab 1 are the first of a long list of successful experiences involving manned interaction. Hence, the Space Station must be configured so as to continue this method of science operations, that is to accommodate attached payloads and their interactive operations.

We recommend that attached payloads must be recognized and accommodated as high priority elements of the Space Station utilization and that Space Station must provide the systems necessary to utilize fully the eyes and brains of the onboard science crew. Operations

experience gained from Skylab and Spacelab must be used in planning for the Space Station.

International collaboration can provide vital elements of the solar-terrestrial facilities in the Space Station. Canadian, European, and Japanese scientists have contributed extensively to the discipline of solar-terrestrial research since its inception.

NASA should actively solicit international participation in solar-terrestrial Space Station activities through the relevant agencies, and the combined mission model should be updated to include all internationally available payload elements.

A platform in a polar orbit capable of sampling all local times is essential for solar-terrestrial studies. Magnetosphere/ atmosphere interactions occur primarily at high latitudes and these middle and upper atmosphere interactions vary strongly with local time, e.g., aurora, joule heating, and radiation/chemistry/ dynamics processes.

The IOC Space Station should include a variable local time polar platform. Several platform candidates exist, ranging from the Space Station modular platform to the European Retrievable Carrier (Eureca).

Scientific Goals and Approach of Solar-Terrestrial Processes

Background. The Sun-Earth system is broad in its spatial extent and diversity of interactive physical processes. Various facets of these solar-terrestrial interactions are being investigated in such programs as the International Solar Polar Mission, the Upper Atmosphere Research Satellite, and the International Solar Terrestrial Physics Program, but none of these is sufficiently broad-based to tackle the extensive solar-terrestrial input-response problems. The Sun-Earth system can be studied by effectively combining remote sensing techniques, active experimentation, and co-orbital subsatellites with the aforementioned free-flyer missions. The role of the Space Station will be long-term studies of the physical processes that control the Sun and its variability and the many phenomena in the Earth's magnetosphere, ionosphere, and atmosphere that respond to this variability. The Space Station will make a true Sun-Earth observatory possible.

The specific approach will involve several parts. First, the Sun will be studied using remote sensing techniques from the manned station. These will involve close interactive observing by an onboard solar physicist and will utilize high resolution telescopes like the Solar Optical Telescope (SOT) to observe detailed solar features and low resolution full-disk instruments to study solar variability. The magnetosphere will be probed by active experiments on the manned station or a platform, which can accomplish both remote sensing of magnetospheric features and the stimulation of specific magnetospheric, ionospheric, and atmospheric processes. These active experiments will involve the close interaction of an onboard space plasma physicist. The remote sensing techniques will also be utilized in studying the atmosphere where instrumentation will be mounted on both the manned station and a platform in a local-time-varying polar orbit. Investigations carried out on the magnetosphere, ionosphere, and atmosphere can be triggered by solar or geophysical events in which the environment can be substantially changed. More detail on our operations approach is provided later.

Plasma Processes Laboratory. In addition to the studies of natural space plasmas, there has evolved a more general approach to plasma studies for which the Space Stations can offer unique opportunities. Because of the new and enhanced interest in this topic, it is treated in more detail in the following paragraphs.

Plasma physics is a field of science that has developed rapidly over the last 20 years, with the principal impetus coming from spacecraft observations, controlled fusion research, and defense programs. While theoretical plasma physics can deal with many situations, plasma physics observations come largely from laboratory experiments with material boundaries or from naturally occurring phenomena in space. The Space Station Program offers an opportunity to perform active, controlled experiments of basic scientific interest in an unbounded geometry.

In May 1985, a workshop took place at the Joe Wheeler State Park, in Alabama, to identify scientific opportunities for plasma physics experiments in the context of the Space Station. A number of concepts proved to have both scientific interest and a compelling requirement that the experiment be done in space. Representative ideas are nonlinear wave interactions using ion beam antennas, turbulent spacecraft wakes, and a rotating magnetosphere simulation. We emphasize that these opportunities are novel and are different from the traditional emphasis on natural plasmas.

Plasma physics experiments place specific requirements on platforms associated with the Space Station. On a provisional basis, we suggest that plasma physics requirements could best be met by a platform which is essentially a co-orbiting modular platform. This platform would have modest propulsion and attitude control systems that would move a distance of 5 to 40 km from the Space Station while experiments are performed, and then return to the Space Station. An airlock would provide shirt-sleeve access to the facilities in the common module. One might envision a plasma physics experimental cycle to be composed of (1) manned experiment preparation, (2) transit of the platform to its active location, (3) experiments, and (4) return and docking at the manned station. Such a cycle could occur weekly.

A remote location eliminates interference between the experiments and the Space Station and provides a radio anechoic environment. However, the location should not be too remote so that the Space Station can serve as a base for optical and radio diagnostics, and very small plasma probe subsatellites.

Overall, it is clear that a plasma physics platform must contain high power electronics, an energy storage facility, electron and ion beam generators, long antennas, magnet power supplies, and cryogenic support. It is this substantial equipment requirement that leads us to consider one of the modular-designed platforms being designed as part of the Space Station system.

<u>**Solar-Terrestrial Studies from Geosynchronous Orbit**</u>. The intial Sun-Earth investigations in low Earth orbit should be augmented with a geosynchronous orbit platform in the mid- to late-1990's. The geosynchronous platform would include solar telescopes, particle accelerators, wave injectors, chemical releases, coherent scatter radars, tethered satellites, ejectable probes, plasma diagnostic instruments, and a variety of new atmospheric instruments (see Section 2.4). This new capability would greatly enhance and extend the research capabilities of the Sun-Earth observatory in low earth orbit.

A geosynchronous platform permits nearly continuous viewing of the Sun. This capability will enable scientists to study the detailed evolution of solar phenomena as they track features across the entire solar disk. For magnetospheric investigations, the geosynchronous platform will be located at the heart of the magnetosphere and will permit new and exciting research opportunities. Since rapid motion with respect to geomagnetic field lines is greatly reduced, particle accelerators may be used much more effectively to probe for parallel and perpendicular electric fields. For the same reason, coordinated ground-based observations can be accomplished more effectively. Particle beams injected from geosynchronous orbit could be monitored by their subsequent emissions in the upper atmosphere in the auroral zone. In similar ways, the wave injection and chemical release techniques will find new applications in this orbit. The geosynchronous orbit penetrates magnetospheric plasma environments such as the plasma sheet where the acceleration processes associated with the aurora are thought to be located.

Atmospheric investigations would take on an entirely new character when placed in geosynchronous orbit. In this case, the primary focus would center around hemispheric imaging which will enable the dynamics of the entire global atmosphere to be studied continuously. The effects of sudden changes such as magnetic storms or solar flares can be investigated quickly and in a global context. Techniques which permit continuous observations of the Earth's limb could permit height profiles of atmospheric features at all latitudes simultaneously (i.e., a global "slice" of the atmosphere). Global maps of constituents such as ozone may also be possible using adjustable ultraviolet filter techniques with imaging instruments. In addition, ultraviolet imaging techniques would be applicable to studies of charged particle precipitation from the magnetosphere into the atmosphere in the auroral zone.

In summary, the geosynchronous platform could provide a significantly enhanced capability for the studies of solar-terrestrial processes. We expect that a geosynchronous Sun-Earth observatory platform, which includes a manned interaction capability either remotely or at the platform and an extensive data analysis network, will provide a very exciting research opportunity that should be the next step beyond the low Earth orbit Space Station.

Space Station Configuration Requirements

As we have stated in the recommendations, the role of the onboard scientist as an interactive operator of the solar telescopes and active space plasma experiments is crucial to solar-terrestrial research. This fact leads us directly to reemphasize the importance of the attached payload portion of the manned station to our discipline. There needs to be unobstructed viewing of the Sun and the atmosphere as well as a place to locate particle and wave injectors and chemical releases for active probing. The deployment, proximity operation, and retrieval of co-orbiting platforms or subsatellites will also be essential for active space plasma and plasma processes laboratory experiments.

An important adjunct to accommodation of attached payloads is an observatory control station in the modules. Previous examples include the multiple docking adaptor console which controlled the Apollo Telescope Mount in Skylab, the Spacelab module active experiment control panels in Spacelab 1, and the aft flight deck console for the control of the solar instrument cluster on Spacelab 2. An area in the manned modules must be included in design studies where the onboard solar and space plasma scientists can operate the cluster of solar-terrestrial instruments. We anticipate the need for six video and color graphics monitors, two computer control keyboards, and a variety of instrument unique control panels filling the equivalent of about four Spacelab racks (about 3 m^2).

A second requirement on the manned modules will be an area in which instrument calibration can take place. This is particularly important in the case of the high accuracy solar output monitoring instruments where stabilized light sources and high precision techniques for measurement of apertures and cavity absorptivities can be used periodically to maintain knowledge of the solar monitoring instrument accuracy over long time periods. It is anticipated that such a calibration area would be useful to other science disciplines and could be part of the internal instrument repair area which has been discussed in the first summer study.

There appears to be a basic incompatibility in the orbit requirements of polar platforms for the solar-terrestrial and the Earth observations disciplines. Because of the high local time variability of the auroral particle and heating input as well as the chemical changes, a high inclination orbit that changes with local time (i.e., not Sun-synchronous) is required by our discipline. After detailed discussions with the Earth Observations Team, we conclude that more than one polar platform will be required to accommodate both groups of instruments. We recommend that two types of polar platforms be considered initially -- one at a Sun-synchronous location appropriate for Earth observations, and one that varies in local time appropriate for our middle and upper atmosphere and magnetosphere investigations. The modular platform that is being designed as part of the Space Station and the Eureca are two candidates that should be considered for our use.

Operations Approach for Solar-Terrestrial Processes

In the following paragraphs, the solar-terrestrial processes discipline begins to lay out its ideas for operating the manned station, a polar platform, and a variety of co-orbiting platforms. These operational descriptions have been divided into sections covering solar physics, solar variability studies, space plasma investigations, and atmospheric observations.

Solar Physics. The Skylab experience was highly successful for the solar physics community and set the pattern for subsequent multi-instrument missions like Spacelab 2, Sunlab, SOT, and ASO (including the Pinhole/Occulter Facility). We recommend to NASA and to other scientific disciplines a thorough review of the Skylab and Spacelab operations to identify the good and bad features relevant to Space Station operations.

Three modes of operation are anticipated. First, there will be automated synoptic observations which are full-time, continuous with moderate (daily average) data rates for a solar cycle or more. Second, scheduled campaigns will be carried out which are planned months in advance and involve full-up operations. They will utilize one full-time crewmember for choosing aim points and instrument modes. The duration of a scheduled campaign will last from 1 day to 1 month, depending upon scientific objectives. Third, unscheduled campaigns based on targets of opportunity will also be carried out. These will be conducted in the same manner as scheduled campaigns, but will be initiated in response to solar activity, on short (seconds to hours) notice.

For solar operations, uplink control from the ground could be extensive in the absence of crew operation of the instruments. Continuous viewing and data recording will be required during sunlit time. The solar instruments will generate up to several hundred million bits of data each second. Part of this, including video, should be brought to the ground in real time for use by ground-based observers. Commands, data, and instructional material will need to be uplinked. We suggest that the primary, high-rate data could be recorded onboard on laser disks. Shuttle flights will bring up new disks and return the recorded ones.

We anticipate that there will be a long-lived, central data archival and distribution facility where a catalogue, data, and software will be available for distribution. It is possible that complete data sets can be distributed on standardized media in standardized formats. Representatives from each instrument may need to be located at the central facility during operations to analyze data and initiate commands to be sent to the Space Station. The use of the telescience philosophy for remote control and data analysis should be utilized to the fullest extent possible. Problem-oriented workshops involving different science teams could give easy data access to all interested scientists.

The onboard science crew will be needed for a large variety of tasks including installation and checkout of facilities, maintenance and repair, integration of new or replacement instruments, calibration of instruments and/or detectors, assembly of large instruments, and, especially, interactive observations, making use of a crew-member's capability to optimize the quality and value of the acquired data . It is obvious that solar physics observations on the Space Station will be highly manpower intensive.

<u>Solar Variability Studies</u>. A set of solar variability monitoring instruments will operate continuously for synoptic studies with minimal changes in data rates or pointing. The long duration and excellent observing conditions of Space Station make it ideal for these studies, some of which may be with operational instrumentation. Higher data rates might be useful for some instruments in response to transient conditions. It may be desirable to include a small telescope operating primarily at H-alpha and adjacent continuum with video display to give the crew a more complete picture of solar activity.

Space Station presents the first opportunity to conduct a complete instrument calibration in space allowing us to greatly exceed the currently achieved precision over longer (years to decades) time scales. Such improvements are required to (1) study possible trends in total solar output of climatological interest, and (2) study the UV flux variation over the solar cycle of critical interest to aeronomy. The radiometric calibration facility might include an optical bench, a stabilized laser, and some UV lamps and reflectance-measurement apparatus. A clean environment and access to a measuring microscope and scanning electron microscope (for metrology of apertures) are essential.

Space Plasma Physics. For space plasma physics investigations using the Solar Terrestrial Observatory (STO) there will be both planned campaigns and event-driven campaigns. Planned campaigns are the week-long periods, occurring once per month, during which two 3-day activity periods are separated by a data analysis/ replanning day. Each campaign is designed to address carefully posed questions in space plasma physics with specific active experiments. These campaigns will require one crewmember for a 12-hour shift. A typical planned campaign is illustrated in Figure 2-1.

Event-driven campaigns are 9- to 10-day periods, designed to actively probe the magnetosphere, ionosphere, and atmosphere during periods of geomagnetic activity that follow large solar disturbances. Under these unusually unstable conditions, a relatively small perturbation may cause large changes in the Figure 2-1 magnetosphere, ionosphere, and atmosphere. For example, particle, chemical, or wave injections may lead to the transfer of energy from the distant magnetosphere to low altitudes.

The occurrence of large flares, filament eruptions, coronal transients, or coronal holes on the Sun will put solar-terrestrial instruments and the investigator teams into a "storm alert" condition. If a large shock passes a solar warning satellite at the L1 libration point in the solar wind, the investigator teams will prepare for previously planned experimentation. These event-driven campaigns will require the efforts of one crewmember for 12 hours a day for approximately 7 days. Two examples of event-driven investigations are shown in Figures 2-2 and 2-3. Each

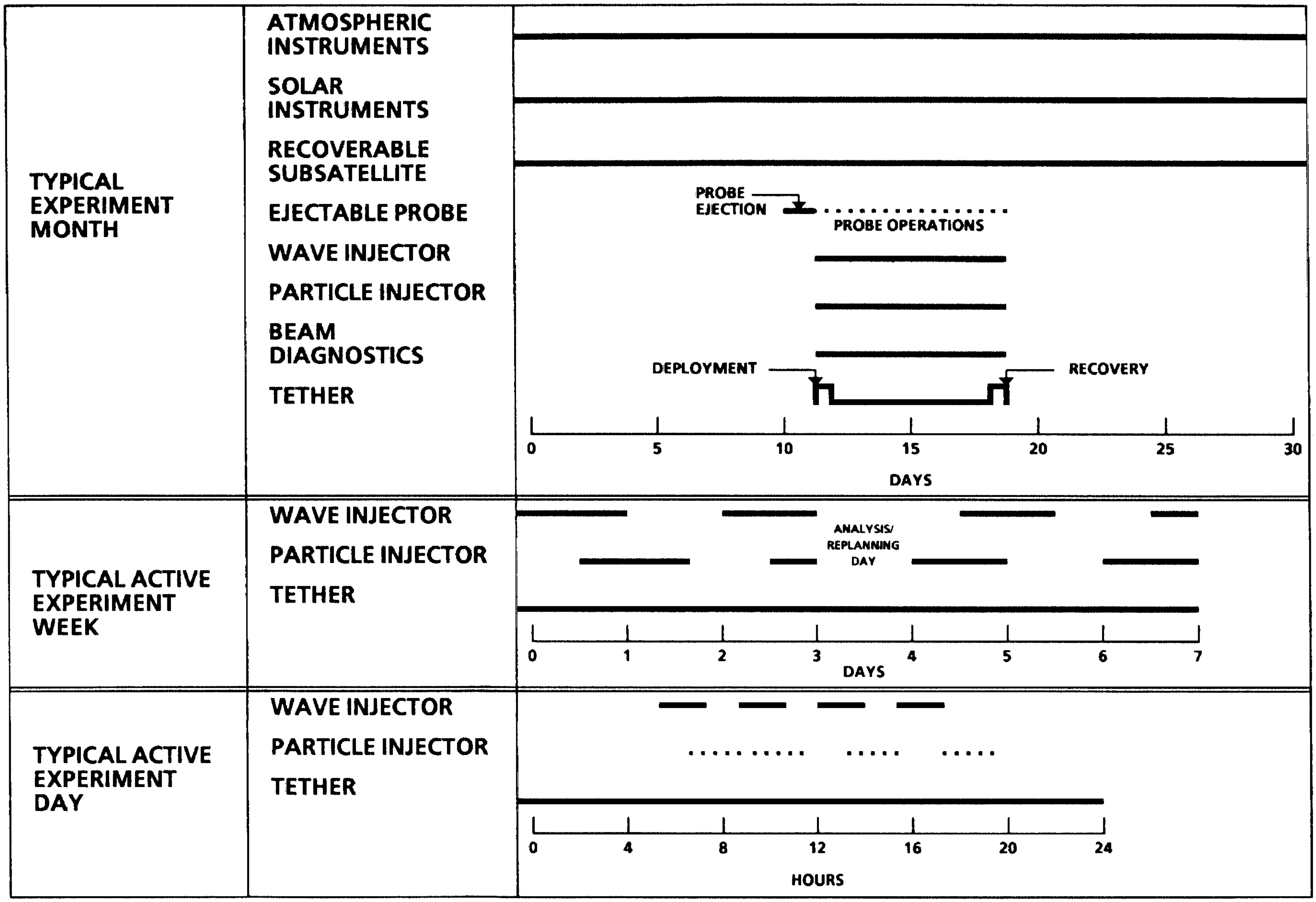

Figure 2-1 Planned Campaign Mode Operations with STO

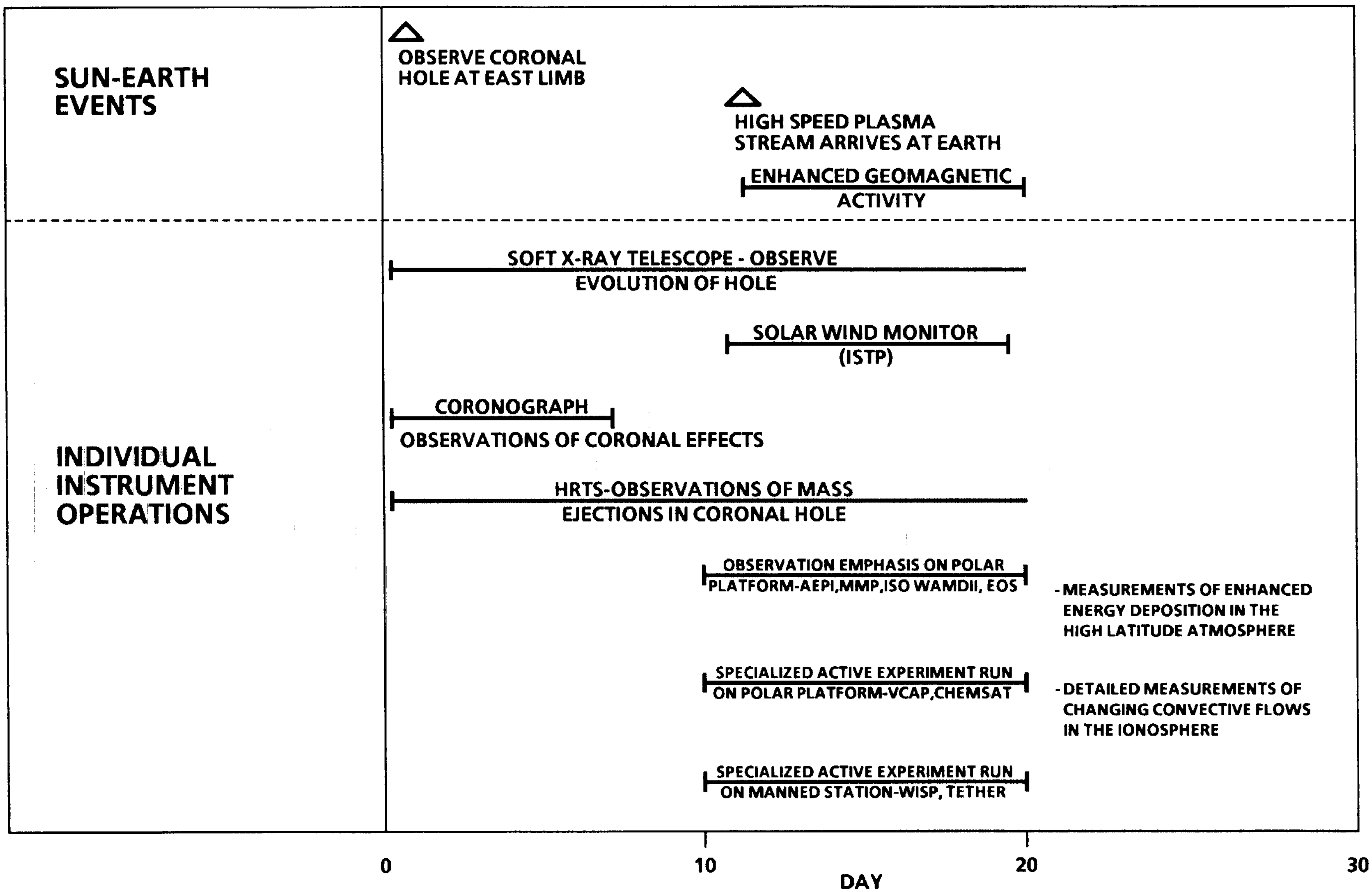

Figure 2-2 Coronal Hole Triggered STO Operations

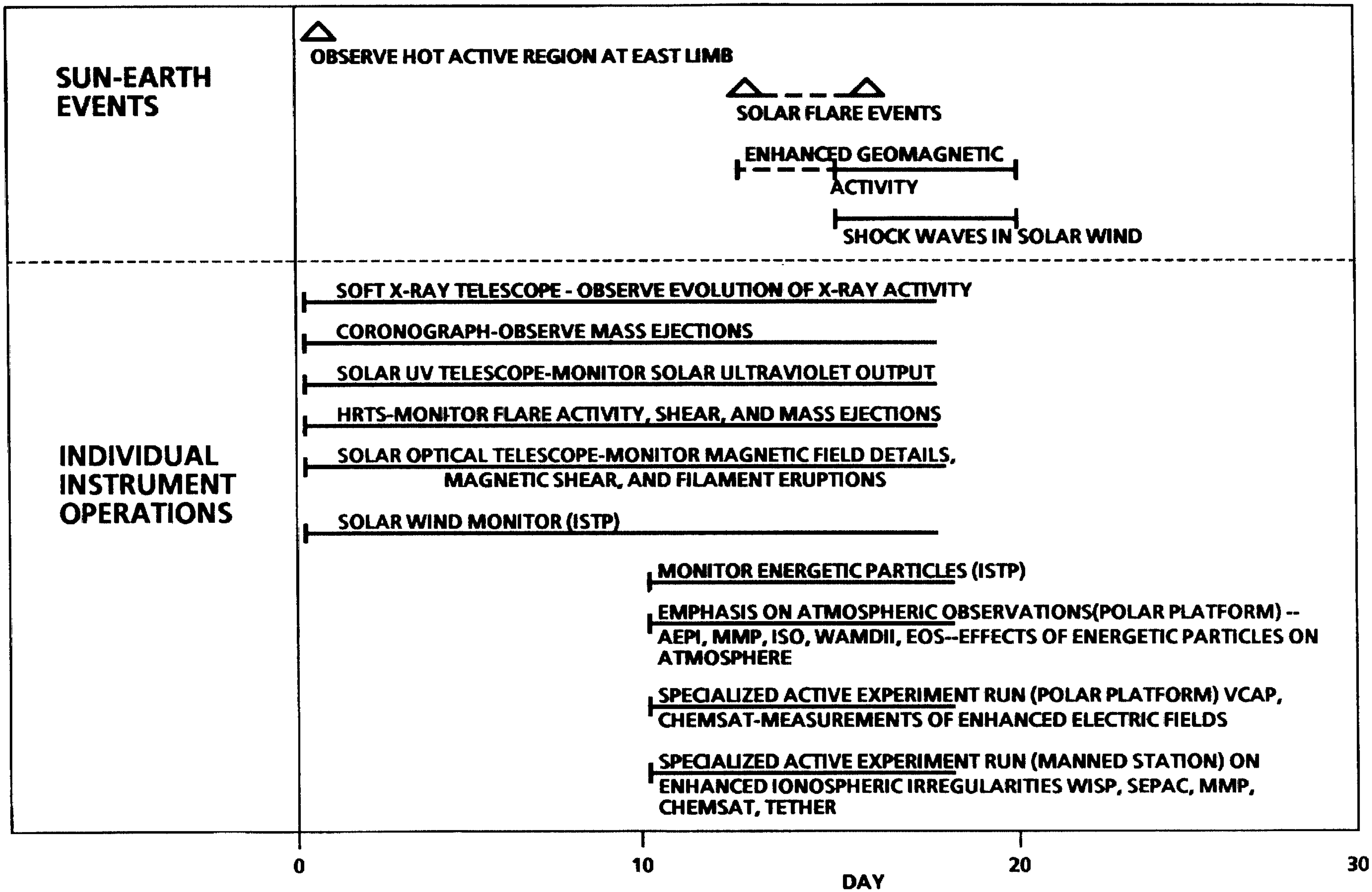

Figure 2-3 Solar Flare Triggered STO Operations

involves the use of the solar telescope cluster, the full disk solar monitoring instruments, the active plasma investigations and the atmospheric observing instruments.

In all of the space plasma investigations, the onboard scientist is an essential element of the operation. A further description can be found in the results of a mini-workshop on STO operations.[1]

Atmospheric Science Applications. Most of the atmospheric science instruments of the STO will be mounted on a polar platform and will be operated entirely from the ground. The basic modes of operation will fall into three main categories:

(1) The first is the "observatory" class of observations which provides a data base for a broad range of investigations ranging from one-shot sequences to quantify an atmospheric process, to long-term studies of diurnal, seasonal, or solar cyclic responses of the atmosphere. The atmospheric instruments would operate for periods of hours to days at an average data rate of 300 kbps.

(2) The "event" class of observations would be a set of measurements triggered by some natural event (e.g., solar flare or solar wind event detected by a satellite outside the magnetosphere). The instruments would operate for a period of several days at an average data rate of approximately 300 kbps and would be commanded from the ground-based control center where interaction with the solar-terrestrial scientist onboard the manned station would also take place.

(3) The final operational mode is the "watchdog" mode of observations in which the instruments operate at a low duty cycle to monitor specific features which provide either temporal morphology or triggers for the "event" class. The average data rate would be approximately 10 kbps.

In addition to the polar platform instrumentation, significant scientific benefit can be derived from a subset of atmospheric science instruments mounted on the manned station or co-orbiting platform. These instruments would permit

[1] Solar-Terrestrial Observatory, Space Station Workshop Report, W. T. Roberts, August 1985.

characterization of the mid- and low-latitude diurnal variations. In addition, these instruments will support active experiments and provide the basic monitoring of the induced Space Station environment. An average data rate would be 10 to 20 kbps. The atmospheric experiments located on or near the manned station can be operated either from the ground or by the onboard crew.

Quick Adaptive Science. Investigations in solar-terrestrial processes lend themselves to quick adaptive science. Our goal is to have a complement of instrumentation at the Space Station for observing the Sun, magnetosphere, and atmosphere. This complement will be operated in a myriad of different ways to study different solar-terrestrial phenomena. The event-triggered operations are adaptive in their response to solar flares, coronal holes, and magnetic storms. The active experiments are inherently adaptive in the laboratory sense with new information coming from prior active investigations being used to plan the subsequent investigations.

It will be possible for scientists to prepare investigations that utilize the onboard equipment in different modes and combinations. In this sense, the Space Station becomes a laboratory for solar-terrestrial research, equipped with the best complement of instrumentation, exposed to the environment that it studies, and available for long periods of adaptive operation to accommodate a continuing series of investigations.

Small carry-on investigations, such as the handheld camera with grating to study Shuttle glow on Spacelab 1 and the orbiter television studies of the aurora on Spacelab 3, are possible and would offer an excellent opportunity to involve new scientists in the Space Station activities. The presence of a scientific airlock on the station would greatly facilitate these small adaptive investigations. The team endorses the idea of quick adaptive science and feels that the solar-terrrestrial discipline lends itself readily to this method of space science research.

Solar-Terrestrial Processes and Space Station -- An Excellent Match

At the beginning of the TFSUSS study activities, the group was asked to identify those scientific areas which are "facilitated by the presence of the Space Station." Solar-terrestrial processes is certainly one of those areas and, in fact, is an excellent match with Space Station capabilities. This feeling is confirmed even more with each flight of Spacelab, where onboard scientists conduct interactive observations of the Sun, the surrounding space plasmas, and the atmosphere below. The use of payloads attached to the manned station in conjunction with instruments on the co-orbiting and polar platforms is the ideal research approach in our discipline. When combined with the free-flying spacecraft of the International Solar Terrestrial Physics Program and Upper Atmosphere Research Satellite missions, the Space Station studies will present a truly exciting opportunity for the 1990's.

Our need for manned operations, large instrumentation, complements of instruments, on-orbit recalibration and repair, deployment and retrieval of subsatellites, and a data system to bring all the information together makes the Space Station very important for our science and furthers the attractive merger of manned spaceflight and space science during the next decade.

2.4 EARTH OBSERVATIONS

The Earth science research community is entering an era in which national boundaries are becoming less and less distinct. Research in this field is on the verge of broadening to include problems that are truly global in scope, in addition to a second generation of studies of regional and local questions -- the original area of concentration. Indeed, it is a measure of the state of maturity of space-related Earth science that for the first time it is possible to study the Earth as a single integrated system.

It is clear that if progress is to be made in this global Earth-as-a-system sense, international cooperation between Earth scientists, and therefore the agencies governing their respective national or regional space efforts, will be essential. It is also clear that this degree of international cooperation must be reflected in how the Space Station system is constructed and how it is operated.

In the following portions of the report, the results of the summer study considerations of the Earth Observations Team, our comments, are based on updated information presented by NASA on the current state of Space Station system planning. The comments are divided into sections on NASA program plans, configuration, operation, telescience, and geostationary orbit opportunities; the latter pointed toward post-IOC augmentations to the IOC capabilities.

NASA Program Plans

To accomplish space-based Earth science research, be it via the Space Station system or otherwise, three major elements are required: (1) adequate sensors, (2) an appropriate data system, and (3) a well-defined science program. The working group's findings with regard to these three are as follows:

- **Sensors**. The Earth Observing System (EOS) continues to be the appropriate space sensor complex for the research program. However, the opportunity for less complex observations from low inclination Space Station system elements will also be required from time to time.

- **Data System**. Since the last TFSUSS summer study, significant progress has been made toward achieving an adequate data system. The formation of a committee by NASA Codes S, E, and T (SET), and the beginnings of the definition of the Space Station Information System (SSIS), including the Science and Applications Information System (SAIS), are welcome steps toward achieving a complete and well-integrated data system. However, little thought was evident regarding the system components on board the polar platforms. Further, though the direction of progress toward SAIS appears to be excellent so far, the magnitude of the progress is not adequate. It is recommended that a greater level of effort be devoted to this task. More specific comments are contained below.

- **Science Program**. The program specified by NASA at this time consists exclusively of the Earth System Science Program. This is an excellent program, well thought through, and most timely. It also appears well mated to the EOS set of instruments.

However, the EOS system, an instrument system of substantial cost, is quite well suited for supporting a much broader program, thus providing a much greater science return. Doing so would serve a much larger scientific constituency, thus helping to assure EOS availability over the substantial period for which it is required by the objectives of the Earth System Science Program. This could be accomplished by adding elements to the program that deal with regionally and locally oriented science questions, and also elements related to applications research.

There is also the need to begin developing a proper interface between NASA and the commercial Earth observational community. This community, though slow in developing to this point, now appears poised to become a substantial force. Lack of such preparation will leave the NASA program in an adversarial, defensive position relative to this community, whereas proper preparation can lead to a mutually beneficial, cooperative relationship. We emphasize, though, that creating an applications research effort and establishing an effective interface with the commercial sector are two distinctly different activities.

Further there is the need to begin immediately the fundamentally oriented ground-based research activities needed to prepare for these IOC activities.

Configuration

Over the year since the previous TFSUSS summer study, the configuration of the Space Station system has continued to evolve. The fundamental elements of the system remain, but the fashion in which they will be utilized has matured significantly. In particular, from a position of relatively lower priority, the polar elements have moved to a position of considerably enhanced importance, based on the size and significance of the potential user community. It now appears clear that at least two, and more likely three, polar platforms will be needed as early as possible in the program in order to meet the needs of the broad and diverse Earth observational user community.

The breadth and diversity of this user community substantially increase the complexity of the system configuration design. Key elements of this design problem include:

- **Accommodation**. The polar platforms must flexibly accommodate a wide variety of instrument types. Examples are: active and passive; optical and microwave; high resolution and modest resolution; and research and operational. Each of these instrument types has different environmental requirements that the platforms must meet in terms of power, duty cycle, platform stability, frequency of servicing, data rate, and data volume.

- **Orbital Parameters.** Almost all Earth observational users require a Sun-synchronous type of orbit. Among the Sun-synchronous group, there are bona fide requirements for orbits providing at least one morning and one afternoon equatorial crossing time.

- **Orbital Altitude**. Requirements here are strongly influenced by (1) the sensor distance from the Earth surface, (2) the possible Earth surface cover repeat cycle times, and (3) the relative ease of service access from STS, among others.

- **Instrument View**. The platforms must provide the capability for view directions from nadir to Earth limb, and provide for a wide range of fields of view. Further, both scanning instruments and those with very precise, stable pointing must be accommodated.

- **Data System**. There are bona fide scientific requirements for very high data rates, to 300 Mbp for short periods, and for delivery of data to user sites in near real time. The data system must also be designed to support the telescience concept for Earth observational research.

Thus it is apparent that the polar orbiting complex of the Space Station system must be designed to accommodate a great deal of diversity and flexibility of use. From the science standpoint, perhaps the most difficult of these diversity of conditions to meet is the accommodation of both research and operational sensors on the same platform. Operational instruments require a fixed and relatively more simple configuration and operational environment. Research instruments tend to require just the opposite, i.e., an emphasis on flexibility and sophistication. Further, it is inherent in the character of these two that benefits of operational systems appear as more immediate, while those of research seem more distant. Thus, as has frequently occurred in the past, operational systems are given priority in the compromises of both system design and operation. It is essential to the ultimate success of the Space Station Program that this not occur, and that a balance be struck in the various design and operations trade-offs that does not provide excessive harm to the science.

Though the major amount of Earth observational data will unquestionably be obtained from polar orbit, the capability for observations from the Station itself or its co-orbiting platforms will also be essential, both because of the more frequent access to space, and because the equatorial region is of special interest in many respects relative to Earth science. Such observations will be critically important for short-term observations including the testing of new instrument concepts, and for the more intense data collection from the equatorial region.

Operations

Since the emphasis in the Earth observational area is on devices on the (unmanned) polar orbiting platforms, the context within which operations matters are considered is quite different than in the case of science related to a manned platform. For Earth observational space operations, the emphasis on the environment and human interface problems on board a manned platform shifts to the environment and human interface problems on the ground. Further, a dominating characteristic of Earth observational research is the volume of data and the diversity of data sources that must be smoothly interfaced and economically operated and maintained for long periods of time. Some data will be able to be collected in the principal investigator, experiment-specific sense, but a much larger amount must be collected under an international facility mode of operation, since there will be a large community of Earth scientists who require access to it. Based on the plans presented to us, specific areas of concern that need additional attention and revision are:

- **Access to Polar Orbit**. Given the much more substantial complexity of systems to be in polar orbit, the limited Shuttle availability to polar orbit appears to be emerging as a substantial limitation. The delay in repair or replacement of instruments on polar platforms would seriously degrade planned science experiments. Most experiments require the use of combinations of instruments for study of interactions of vegetation influences on climatic changes. Downtime for individual instruments thus takes on added significance.

- **Servicing**. The systems in polar orbit will be some of the most complex ever placed on unmanned platforms, and they must function effectively for many years. There will be many needs for timely and reliable service in support of Earth observational experimentation, as well as commercial and operational equipment. These needs include replacing, repairing, and adjusting equipment; periodically calibrating equipment; testing new sensors; and moving instruments from one platform to another.

- **On-Time Start**. There are substantial reasons in both the operational and the research Earth observational arenas to raise the importance of an on-time start above the ordinary.

- **Global Scope of the Data System**. The Earth science of the 1990's will have as a major component the study of the Earth as a system, and individual experiments will encompass large portions, if not the entire Earth. Data will be needed from remotely located ground and airborne sensors, in addition to spaceborne ones, and data from existing data bases located around the world will be essential. The information system to capture such data and rapidly transmit it to the scientist will be fundamentally important to understanding the many global processes.

- **Onboard Processing Policy**. As previously indicated, large quantities of data will be generated on board the platforms. This large volume of data tends to suggest the need for accomplishing as much onboard processing as possible, in order to simplify data transmission. While onboard processing is expensive to achieve, the facts that flexibility is required for a good quality research environment, and that different researchers will need the same data processed in different ways, suggest that raw data should be transmitted to the ground, where flexible processing is cheaper. At this time, there is no evidence that a policy or rational basis has been developed for making specific decisions on the design of onboard processing capabilities. Without such a policy or rationale, it is inappropriate to begin making individual decisions on how the onboard processing system should be designed.

Telescience

It is apparent from the foregoing, that telescience has a somewhat different meaning in the Earth observational context than it does within the context of research involving combined human activities on orbit with those on the ground. It is, nevertheless, an equally valid and important concept, for the essence of the concept is a tighter, more effective relationship between researchers and their apparatus.

In the case of Earth observations research, apparatus consists not only of sensors gathering data in space, but of data, frequently in very large quantities, that may have been gathered at a different time, at a different place, from fundamentally different types of instruments, and that may only be available in data bases at distant locations. It may well involve two or more researchers of different Earth science disciplines at separate locations working in a coordinated fashion.

It is thus important that the principles of telescience be studied and pursued in this context, as distinct from the original context of the researcher in his home laboratory, working in coordination with a mission specialist operating experimental apparatus on board the Space Station. The positive return that the concept can produce is to make the science more productive and cost effective by permitting the researcher, in the familiar surrounding of their own laboratories where they have the tools to be maximally productive, to proceed most rapidly through the productive iterations of trial, observation, reformulation, and retrial.

Closure

The team believes and expects that the Space Station era can be an exciting and highly productive era based upon the establishment of the EOS and associated program elements. It should be a time when innovation is the watchword, based upon a carefully planned research environment containing (1) new, advanced instrumentation, (2) an effective data system implementing the telescience concepts, and (3) a science program in which the researchers have the needed freedom of operation and the opportunity to rapidly pose questions and iterate the experimentation to successful conclusion.

Geostationary Orbit Opportunities

The Earth Observations Team examined the value of the geostationary orbit as a vantage point for future Earth observations. The team concluded that there are substantial advantages that this type of orbit can offer, given that it is now becoming technologically reasonable to build the needed sensors. Among these advantages are the following:

- High temporal resolution observations. Observations of changes with time constants of minutes would be possible for the first time for land areas, and in substantially enhanced fashion over that previously possible for oceans and atmospheric phenomena.

- Sharply reduced cloud interference to land and ocean observations.

- Selectable viewing times and frequencies of view.

- Use of anisotropic and/or thermal inertial characteristics of the surface and atmosphere as independent pieces of information.

- A consistent viewing geometry to any Earth location. This would simplify the analysis and interpretation of data.

- Observations with selectable dwell times. Lengthened dwell time can be used to improve spatial resolution to the diffraction limit, to obtain very high signal-to-noise ratios, and/or to make possible high spectral resolution measurements.

- Nearly instantaneous coverage over large areas. Many small-scale, rapidly changing events could be surveyed quickly enough that their interactions with each other and the surrounding environment could be determined. For example, episodic events thus become detectable and monitorable.

- Reduction of calibration difficulties, since a single sensor that makes a particular type of measurement (e.g., cloud growth monitoring) may be used throughout a measurement sequence.

- Stereography, where two geosynchronous platforms are located near each other so there is overlap in coverage. This has already seen successful demonstration in the case of cloud stereography from Geostationary

Operational Environmental Satellites (GOES). However, the advent of high-resolution devices would substantially increase the utility of such stereography.

- Simplification of the data system, since the observation platform can function as its own data relay satellite.

Complete coverage between 50°N and 50°S with reasonable viewing angles would require about six satellites. However, geosynchronous platforms are, of course, regionally oriented devices, just as is the larger portion of user interest.

Due to the distances involved (36,000 km to the Earth's surface), only passive methods would be used, and large telescopes and antennas would be needed. Here, again, the facilities of the Space Station, with the ability to assemble, test, and then deploy to geosynchronous orbit, would be important to the success of these instruments. Indeed, the Space Station is seen as one of the keys that helps unlock the possibility for such observations. The following material contains some more specific comments on the uses for observations of the Earth from geostationary platforms.

<u>Meteorological Utilization</u>. Geosynchronous satellites are capable of obtaining data over large areas with high spatial and temporal resolution. Therefore, they are the best satellites for determining meteorological parameters that are associated with small-scale and/or rapidly changing events . These events include severe thunderstorms, other mesoscale convective systems, tropical and extratropical cyclones, frost and freeze situations, fog, and dust storms. Many of the measurements taken in association with these events can be used to detect and predict other localized phenomena, such as orographic effects, and lake and sea breezes. The data can be used to initialize regional-scale and mesoscale models. The realism and sophistication of these models is progressing rapidly, and by the late 1990's they will require the suggested observations. Also, some of the measurement requirements for synoptic- and hemisphere-scale meteorological systems and climate (e.g., winds and diurnal cloud changes) are met with geosynchronous satellite data.

Table 2-1 gives a list of observation requirements when several thunderstorms are occurring. It is apparent from Table 2-1 that high horizontal and temporal resolutions are needed, and realistically, only a geosynchronous orbit can satisfy the temporal requirements. This example of requirements is one of the most difficult to satisfy since the significant portions of severe thunderstorms are small-scale and evolve very rapidly. When these needs are met, many of the requirements for other mesoscale phenomena are also satisfied. There are tables similar to Table 2-1 for other mesoscale phenomena. When the observational requirements are translated into instrument parameter requirements (e.g., spatial resolution, signal-to-noise, etc.), some of the horizontal and temporal resolution requirements become even higher. A good example is the derivation of winds from cloud motion where < 1 km sensor horizontal resolution is needed to track small clouds to produce wind estimates on coarser grid scales.

During the 1990's, the United States will have the next generation GOES operational satellites in orbit. The instrumentation will consist of an infrared sensor for measuring atmospheric temperature and moisture profiles, and another sensor for which the principal functions (besides providing routine images) are determining surface temperature, winds from cloud motions, cloud properties (amount, type, and height), and some precipitation information. In addition, during the 1990's, it is anticipated that some research sensors will be flown that include microwave temperature and moisture profiling and imaging (principally for precipitation), ozone mapping, lightning mapping, and a next generation infrared profiler to provide higher vertical resolution. Thus, for Earth observation sensors for the Space Station geosynchronous platform we should consider those that are more advanced than both the operational and expected research instruments mentioned above. Naturally, if the research instruments mentioned above have not flown, they could be candidates for the platform.

While these expected developments in the 1990's will result in a major increase in meteorological sensing capabilities, a number of substantial measuring deficiencies will remain that can be addressed only by another enhanced level of instrumentation. The early generation microwave profiler will provide temperature profile nadir resolutions in cloudy areas of about 35 km and moisture profile resolutions of approximately 20 km. However, resolutions of 5 km (see Table 2-1) are required.

TABLE 2-1
OBSERVATIONAL GUIDELINES FOR SEVERE LOCAL STORM

PARMETER	RESOLUTION (km or min) Horizontal	Vertical	Temporal	ABSOLUTE ACCURACY
Temperature:				
• Surface	5-15	NA	10-30	1-2 K**
• Profile, General	10-50	1-5*	30-120	1-2 K**
• Profile, Thunderstorm and Immediate Vicinity	5-25	1-5*	1-10	1-2 K**
Moisture:				
• Profile, General	10-50	1-5*	30-120	5-15%RH
• Profile, Thunderstorm and Immediate Vicinity	5-25	1-5*	1-10	5-15%RH
• Lower Tropospheric Moisture Gradient (e.g., Dry Line)	3-15	NA	5-30	10-25%RH
Winds:				
• Boundary Layer	5-20	0.2-1	5-30	1-3 m/sec
• Above Boundary Layer	10-50	1-5	15-60	1-3 m/sec
Precipitation:				
• Rate	3-50	NA	3-30	20-50%
• Type	1-10	NA	1-10	Rain/Hail
• Yes/No	5-50	NA	6-60	NA
Cloud Top Height	0.5-10	0.25	0.5-15	250-500 m

*Need 0.5 km vertical resolution for inversions

** Relative accuracy is one-half these values

Reference: Shenk, W. E., R. F. Adler, D. Chesters, J. Susskind, and L. Uccellini, 1985, "The Rationale and Suggested Approaches for Research Geosynchronous Satellite Measurements for Severe Storms and Mesoscale Investigations," NASA Tech Memo 86185, Goddard Space Flight Center, Greenbelt, MD, 29 p.

Thus, much larger microwave antennas are required beyond the initial plan for a 4.4 m antenna. An antenna of about 40 m is required to achieve resolution of a few km if the 118 GHz region is used for temperature profiling. The 183 GHz region is needed for water vapor profiles and the resolution would be <2 km. For precipitation mapping, 1 to 3 km horizontal resolution is needed to resolve individual convective cores. With high frequency microwave (i.e., 183 GHz), this resolution can be achieved with the 40 m antenna. With this resolution, it should be feasible to track small precipitating convective cells over water underneath higher clouds to obtain winds. These could be especially valuable in storms (e.g., tropical cyclones). A 40 m antenna designed for high frequency microwave measurements will require assembly and extensive testing in low orbit before deployment in geosynchronous orbit.

Another capability needed for the detailed precipitation mapping of convective areas (which is the most demanding type of precipitation determination) is high spatial and temporal resolution for both visible and infrared imaging. The time history of convective growth is related to the subsequent precipitation volume produced by a convective cell. Resolution of 1 km is required in the 11-micron infrared region to accurately monitor the vertical rise rates of the cells. Achievement of this resolution requires a >1 m optical diameter telescope that is diffraction limited. This telescope is also needed for solving another major deficiency area, which is the resolutions needed for accurate cloud motion-wind determination (both day and night), to sharply improve surface temperature mapping, for much better cloud property determination, and to monitor convective growth in general (in addition to the precipitation requirement mentioned above). The pacing horizontal resolutions are 200 m in the visible and 500 to 1000 m in the 11-micron infrared region.

The final major deficiency that can be addressed by the data from the platform is inadequate vertical profile resolution. Even the next generation profilers with 2 cm^{-1} spectral resolution are not expected to completely solve this problem. The best remote sensing solution is lidar profiling, but this is not yet practical from geosynchronous orbit. Therefore, the best approach is the next (and probably ultimate) step in passive profiling beyond the 2 cm^{-1} spectral resolution approach, which is to resolve the wings of individual absorption lines with 0.2 cm^{-1} spectral resolution in the 4.3-micron CO_2 absorption region. Vertical resolutions of 2 to 3 km are possible (compared to 1 to 2 km with lidar). As Table 2-1 shows, this will cover about half of the range of the requirement of 1 to 5 km. Another instrument that will contribute significantly to improving the accuracy of temperature profiling is ozone mapping. An independent estimate of the tropopause height from Nimbus 7 ozone data has been shown to improve the profiles by about 1 K in the upper troposphere and lower stratosphere. In addition, the ozone data are extremely useful for estimating strong wind gradients associated with the jet stream, and in detecting and tracking volcanic eruptions.

Besides improving the major deficiencies for some of the traditional parameters, there are some important special measurements that can be made. A sensor that could be used for lightning mapping, trace gas detection, and mapping is a small instrument using area arrays of 2000 by 2000 detectors that could provide data with a ground resolution of 5 km. This would provide a field of view of 10,000 km in the spectral region of 200 nm to 1000 nm. The telescope would have a focal length of 200 mm and an aperture of 5 cm. The spectral selection would be done using a filter wheel with filters appropriate to the observation needs.

As time and industrialization progress, the measurement of global pollution becomes more and more important. It is well known that the sky radiation is highly polarized at an angle near 90° from the Sun. Aerosols and pollution depolarize this radiation and, thus, these sources can be readily identified. In principle, it should be possible to trace pollution plumes using this technique.

<u>Land Surface Utilization</u>. The primary utilization of Earth survey data from geosynchronous orbit would be to monitor transient or episodic events that are not normally possible to monitor with the repeat cycle of a lower orbiting satellite over a given location. The geosynchronous orbit will also allow the sharp reduction of cloud and atmospheric effects, the use of anisotropic properties and thermal inertia of a scene as additional data sources, and the survey of stress-related events that need flexible viewing times.

A number of important land-related vegetation phenomena can be reliably observed only by sensors mounted on geosynchronous platforms. Thermal phenomena such as freeze damage, and drought-induced canopy temperature elevation, occur for relatively brief periods during the day and can be monitored only by utilizing the finer scales of viewing frequency offered by geosynchronous platforms. This capability also permits monitoring key vegetation-related events that occur during relatively narrow phenological windows of 2 to 3 days. Some important examples of such events are forest infestation by the Gypsy moth during the leaf extension state of deciduous trees, and the effect of high ambient temperatures on crop yields during wheat grain filling or corn pollination.

Selectable viewing times permit the observation of drought-induced wilting of vegetated canopies which, during the early stages of drought, occurs only during maximum daytime heating in the afternoon. For the remainder of the day, the canopy may appear totally normal.

Episodic events such as flooding, fire, and wind-driven soil erosion could only be observed given the flexible viewing schedule of the geosynchronous platform.

The continuity of viewing throughout each day also permits the best possible atmospheric conditions to be obtained for surface observations. This is extremely important since absolute radiometry needed for observing a host of vegetation phenomena is difficult, if not impossible, under many atmospheric conditions encountered with even daily coverage. For the tropics, of course, more frequent coverage is needed to obtain minimally cloud-free coverage. The geosynchronous platform also provides a unique station from which to acquire multiple illumination and viewing angle data needed to estimate many of the more intractable biophysical parameters such as biomass and leaf area. Snow and ice detection can be improved further by using a combination of very high visible resolution and imaging microwave data. The viewing angles are quite satisfactory for snow at mid-latitudes, and even suitable for detecting ice in lakes and coastal areas probably up to 70° of great circle arc from the subsatellite point. The liquid water content of snow is best measured using microwave. These observations, used in conjunction with very high-resolution visible imaging, have been quite successful in estimating snow-water equivalent of the snow that is not over 1 m deep.

For these land survey observations, the primary sensor will be an imaging radiometer with a clear aperture of 1 to 2 m. This could be the same sensor that would be used for meteorology and oceanography. The length of the instrument will be 5 times the aperture, and the diameter 2.5 times the aperture. This diffraction limited observing system can provide the excellent signal-to-noise required for these advanced studies by adjusting the integration time to provide the required signal. The ground resolutions will be a function of wavelength and aperture size and are shown in Table 2-2 for the various spectral regions covered by the instrument. The nominal field of view for Earth surveys will be 500 km wide and as long as desired.

TABLE 2-2

Spectral Regions (micron)	Instantaneous Field of View (m)	
	1 m Aperture	2 m Aperture
0.4 to 1.0	50 - 100	25 - 5
1.0 to 2.4	100 - 200	50 - 100
3.5 to 4.2	400	200
10.5 to 2.5	1000	500

Each of the spectral regions will be divided into a number of different spectral bands. The 40 m microwave antenna mentioned earlier would be suitable for the snow and ice investigations.

<u>Oceanographic Utilization</u>. The oceanographic utilization of geosynchronous satellite data will focus on improvements in sea surface temperature measurement and ocean color sensing. The estimation of sea surface temperature can most likely be improved to <0.5 K, along with better coverage, with the combination of the large high-resolution imager mentioned earlier for earth survey and meteorological purposes, and the 40 m microwave antenna providing low frequency microwave data.

This accuracy and better coverage could provide tropical oceanographers with a substantial improvement in their ability to monitor and follow events related to the El Niño and Southern Oscillation. One of the primary difficulties in the tropics is the removal of atmospheric and cloud effects, which are intimately tied to evolving ocean temperature fields. With a high-resolution capability and a continuous sampling, many of these problems can be overcome. There are several ocean color features that change with sufficient rapidity to substantially benefit from measurement from geosynchronous orbit. Ocean fronts and eddies, which are important as areas of enhanced fish concentration and for identifying strong current regions, can move a few miles in a day and are more reliably detected from ocean color rather than from thermal signatures. For example, loop currents in the Gulf Stream in the summer become difficult to detect thermally, but are distinguishable from color features. They change location sufficiently in a day to require repeated monitoring. Nutrient concentrations near the ocean surface also can change rapidly, especially those associated with upwelling following the passage of a cyclone. Phytoplankton increases of a factor of two to four in 6 hours can occur in response to wind mixing and near-surface nutrient increases. Estuarial plumes can change dramatically in a few hours caused by tidal advection and changes in the winds. Knowledge of plume location and movement is important for ecology and where sedimentation will occur. For ocean sensing 10 to 20 nm spectral resolutions are required for eight channels between 400 and 1000 nm. Five channels are needed in the thermal infrared for sea surface temperature measurement. The measurements should be taken every 30 minutes. The same large-aperture imager that will support the meteorological and land survey investigations can be used for oceanography.

2.5 LIFE SCIENCES

Life sciences research on Space Station has several different, but related, aspects; it includes both basic and applied research in a wide range of life science disciplines. The applied research focuses on promoting the health, well being, comfort, and productivity of humans in space. Such research includes development of the scientific base for health care on Space Station, as well as self-regenerative life support systems. Basic research uses the unique characteristics of the space environment, including microgravity and special radiation fields, to better understand the function of plant and animal systems. In addition, the origin and evolution of life, as well as understanding the interaction of the Earth's biota with the planet on a global scale, are major concerns for basic life science research.

Basic Life Sciences Research Issues

Human physiology studies are aimed at both understanding normal function with implications for disease, and qualifying people for long-duration spaceflights. In human physiology, a major point of interest for many years has been the homeostatic mechanisms that operate in response to a variety of challenges, stimuli, and perturbations; e.g., ionic imbalance, temperature variations, pressure changes, metabolic demand, lower body negative pressure, exercise, gravitational stresses, circadian rhythms, and microbial infections. Responses are modified by repeated or prolonged exposures to such perturbations. The successfully oriented or stabilized modifications are frequently referred to as adaptations.

Although considerable knowledge about these adaptations has been gained from Skylab and some recent Shuttle experiments, and despite the apparent success of the Soviet long-duration flights, we are still largely ignorant of the mechanisms and limits of human adaptation to prolonged spaceflights. Without this knowledge, we are unable to gauge the possible physiological and behavioral consequences of prolonged human exposure to this environment.

Other considerations are related to the fact that detailed investigation of these phenomena in animals and humans will also have implications for our understanding of disease processes on Earth, as well as in space. Probing the adaptation mechanism of the human system to weightlessness involves, among other things, studying vaso-regulation mechanisms as related to fluid distribution and hypertension; investigation of bone and muscle loss in spaceflight as related to disuse atrophy and osteoporosis; long-term effects on the immunological system; and neurovestibular adaptation and after-effects. The cardiopulmonary system adaptation and function during long-term weightlessness is not only of scientific interest, but also of utmost practical importance for the elaboration of countermeasures to be undertaken against adverse effects of spaceflights on humans. The long-term controlled environment provided by the Space Station will permit major advances in understanding in these areas and the ability to commit to long-duration manned spaceflight.

A microgravity environment is essential to study biological processes that are known to be influenced by gravitational fields, in both plants and animals. While these studies, in some cases, may well be related to the understanding of specific biomedical problems, the primary purpose of these experiments is to learn about basic biological processes in relationship to the gravitational field. In particular, higher plants and animals are clearly gravitationally oriented and responsive, but the mechanisms of sensing, the thresholds of sensitivity, and the mechanism of response of living systems are not well understood because continuing gravitational input makes this type of experiment virtually impossible to perform on Earth.

Related to this objective is the study of life cycles of both plants and animals in microgravity. Long-term (years) spaceflight and/or extraterrestrial habitation will require self-regenerative life support systems; that is, growing food materials through several generations (plant and animal) in the spacecraft habitat. The ability to do this must be demonstrated so that a closed, self-sustaining ecosystem can be designed and developed. The ability of various plants to flower, form seed, germinate, and develop normally to adulthood is necessary for the ultimate development of long-term flight. The radiation environment of such experiments should be monitored and relevant studies conducted on long-term radiation effects, particularly those of high-Z particles, which cannot easily be duplicated on Earth. The timespan for such experiments is necessarily long, from months for the simplest species to years in the case of certain animals. The Space Station alone offers this opportunity in full, although precursor experiments can and are being done on Shuttle and other spacecraft.

An important scientific theme in the life sciences is the study of the origin and evolution of terrestrial life. This involves an understanding of the entire sweep of chemical evolution from the formation of the biogenic elements (C,N,O,S,P,H) during stellar formation, through the processes by which these elements, and simple organic compounds, are incorporated into interstellar grains, comets, meteorites, and other celestial objects, to the formation of macromolecules and self-replicating organic chemical systems on the Earth and elsewhere. Toward the elucidation of many of these processes, the Space Station appears to offer several intriguing experimental approaches. These can be grouped into three general areas: observational studies, in situ experiments, and collection experiments.

Observation of solar system bodies (e.g., comets, asteroids, satellites, and atmospheres of the outer planets), molecular cloud cores and diffuse interstellar clouds, evolved stars, and other galaxies will contribute in a major way to characterizing the evolution of the biogenic elements. Efforts to detect and study protoplanetary and other planetary systems, coupled with searches for manifestations of intelligent life elsewhere in the universe, are of vital importance to the exobiology community, and the planetary and astrophysics communities as well.

In situ experiments conducted on the Space Station core facility would permit fundamental studies of grain physics and chemistry, as well as of the survivability of terrestrial organisms in free space. Also of interest are studies of artificial comets, released and studied from the Space Station. There is again common interest with other disciplines in this capability.

As noted in Section 2.2, collection of pristine extraterrestrial particles, particularly non-destructive collection, could open new horizons in the study of biogenic element evolution both within and outside of the solar system. The unique combination of long exposure, large collecting area, and power afforded by the Space Station makes this new form of study feasible.

Long-term terrestrial observations (see Section 2.4) are of great interest to the life sciences, in that it offers a means of viewing and measuring the biota of the Earth for very practical purposes. It also permits much more precise measurement of the environmental parameters that interact directly with biological processes. Through this mechanism an understanding of the long-term relationship between the evolving planet and its biota, a situation much to be desired in today's world, becomes achievable .

Space Station Design Decisions That Will Impact Life Science Operations

Since the stated purpose of Space Station is to extend our capability for human presence in space, and to increase our ability for scientific study and exploration of the solar system, we should take great care to assure that steps taken in planning at this time are headed in that direction and consistent with this stated purpose. It would seem that the goal of providing a productive working environment for humans in space would mean producing a nearly normal terrestrial environment and relatively normal working laboratory conditions for the space scientists.

Module Atmosphere. The Life Sciences group strongly recommends a normal atmosphere for the modules with approximately "sea level" pressure and typical oxygen, nitrogen, and carbon dioxide content. Any other atmosphere would necessitate extensive and expensive research for ground-based control and baseline data. This is particularly true if the atmospheric pressure is 10.2 lbs per square inch with a 31 percent oxygen content (equal to the sea level partial pressure of oxygen). In this case, it would be necessary to set up chamber facilities for long-term control groups for humans, animals, and plants. Because many investigators would want to use the facilities at the same time, multiple chambers would be necessary. The facilities would need to be both animal- and man-rated, and would be required for the lifetime of the Space Station.

Even if a relatively small reduction in pressure was envisaged, for example 12 lbs per square inch at 21 percent oxygen, the problem of terrestrial controls would still be greatly complicated. This is equivalent to living in Denver, which causes physiological changes in blood gases, red blood cell concentration, pulmonary artery pressure, and ventilation. Some of these differences are greatly exaggerated by exercise. While in some instances a great deal of information is available, in many others additional data would be needed, requiring a permanent research facility at an appropriate altitude. In addition, scientific experiments at such an atmospheric composition on the Space Station would be compromised by the fact that the nitrogen partial pressures and water vapor evaporation rates would differ from the control situation on the ground. This is also likely to require an expensive program to ensure that ground controls are not seriously compromised, or to construct environmental chambers for the ground control experiments.

Another consideration is that the international community appears to favor the normal sea level atmosphere so that any collaborative studies with the Europeans or Japanese would be greatly complicated if this atmosphere was not chosen. In addition, the Soviets use sea level atmosphere so any possible collaboration, such as in a manned Mars mission, would be enormously difficult if we went to a different atmosphere.

The basic reason for considering a lower pressure is the impact of pre-breathing time for extravehicular activity (EVA). Options to reduce the impact exist, such as sleeping at an interconnect module at low pressure, or possibly temporarily reducing the pressure in one habitation module. Another option is to increase the pressure in the suit. Although this may be difficult and expensive, it must be done eventually. Also, a suit with less than 100 percent oxygen would greatly reduce the fire hazard during EVA. It would be short-sighted to design the Space Station, which will have a life of perhaps 25 or 30 years, on the basis of a technical problem with EVA suits that will be eventually solved, and then to have to discard some of the research data gathered in the interim period. The obvious solution to these problems is for Space Station to have a normal atmosphere, and a suit with normal oxygen partial pressure and a partial pressure of nitrogen high enough to completely prevent decompression sickness. Investigators at the U.S. Air Force School of Aerospace Medicine have recently shown that a transition from a normal atmosphere to one with a total pressure of 9.5 lbs per square inch can be made without pre-breathing.

Crew Availability. This is a critical item. We must assess very carefully the purpose of each and every crewmember in anticipation of an extremely heavy work load. If possible, more than six crewmembers are needed. There are undoubtedly a multitude of housekeeping chores associated with life on a Space Station, many of which have not been anticipated or planned for. Our principal interest, however, is in the ability of the crew to perform the scientific and technological functions for which the Space Station is being designed. From the life science point of view, there are two separate and distinct roles for humans in the Space Station. One is as a source of human subjects for investigations. The long-term goal of establishing a safe, productive environment for human habitation in space is of prime importance. While animal models can serve as substitutes for some biomedical research, ultimately many critical or corroborative tests must be done on humans, and in some cases, can only be done on the human subject. This can be very demanding on crew time. Monitoring human behavioral, physiological, and biochemical responses to Space Station life will be a continuing, time-consuming function of many, if not all, crewmembers.

Second, we assume that the crew are the experimentalists who will be conducting and monitoring experiments; servicing, repairing, and modifying instruments; and communicating with colleagues on the ground. Time for these activities must be carefully planned and allocated. It seems to us that the life sciences and microgravity programs should begin to coordinate their requirements for crew time.

We also feel that it is time to begin to study the impact of the complex and exhausting operational protocols of Space Station on individual and group behavior. In this context, psychological factors will become increasingly important. Automation, robotics, and artificial intelligence will increasingly dominate both physical and behavioral features of the space environment. The priority questions that this reality poses are determinations of the optimal mix of human operator instrumental control and human operator independent computerized systems management for each Space Station system. To some considerable extent, these fundamental productivity and autonomy issues are especially important in the formulation of long-term planning. Of more immediate interest would be the development of an experimental data base to ensure effective workplace designs under volume-limited conditions, and to provide for habitable, and hopefully creative, general living accommodations that enhance human growth potential.

From a methodological perspective, one of the more obvious and pervasive research needs related to the influence of the Space Station environment upon productivity and general well-being is the development of assessment techniques for effective performance monitoring. Because the methodology for assessing the processes involved in complex group operations is not developed, research is clearly needed to specify critical indicators and allow for partitioning of performance among individual group members. Even less well developed, but of equal if not greater importance, are methodologies for monitoring and evaluating those behavioral signs and symptoms that reflect the general emotional climate of isolated and confined microsocieties, and that influence task performance and social interactions. There are indications, for example, that structural and functional analysis of vocal utterances was a potentially useful monitoring and assessment approach in evaluating the affective state of cosmonauts in the course of recent U.S.S.R. space missions. Clearly, human behavioral research investments in this critical domain can be expected to yield rich returns in the development of early warning systems to prevent performance degradation and interpersonal conflict.

Quick is Beautiful. Care must be taken to include the possibility of small, simple and perhaps relatively inexpensive experiments. While many life science experiments are long-term and require substantial facilities, this is not always the case. As is often the case in the terrestrial laboratory, one experiment leads logically and naturally into a second, requiring very simple modifications, simple changes in nutrients or solutions, or perhaps minor changes in equipment. The flexibility for this kind of experimental modification and the addition of new experiments as a follow-on to one already performed should be put in the system. As part of this capability, the ability to return samples to the Earth on short notice should also be included. Rapid, small sample returns could greatly facilitate the design of follow-on experiments, and speed up the process of experimentation. It is easy to foresee studies where two or three pilot experiments might greatly improve the final experiment design. This is actually the normal way most experiments are developed in ground-based laboratories. In some instances, the results could be obtained from data or samples transmitted to the ground for analysis. In others, analyses could be made in the Space Station using onboard facilities and scientists. In some cases, complete experiments could be carried out with little investment of time if simple equipment was already available in the life sciences laboratory on the Space Station. Examples of these kinds of experiments are those performed in the middeck of the Shuttle. To carry out quick, adaptive science experiments, it is essential that some space be set aside in the life sciences laboratory -- for example one rack -- and that the time line have some flexibility.

Microgravity. Microgravity is a term referring to the low acceleration level, much less than 1 g found in low Earth orbit. In the Shuttle, the acceleration level is sometimes in the range of 10^{-3} to 10^{-4} g, depending to a large extent on the onboard activities. Microgravity can be used as a basic research tool in trying to understand the relationship between living organisms and the gravitational force. There are two basic questions to be asked: (1) Can plants and animals undergo normal development and life cycles in the microgravity environment and (2) Does the microgravity environment provide a research tool for studies on developmental and other biological processes? It is clear that both plants and animals have evolved mechanisms of detecting and responding to gravity. However, these mechanisms are not well understood. For example, do individual cells perceive gravity and what is the threshold of perception? How is the response to gravity mediated? Does gravity play a determinative role in the early development and long-term evolution of the living system?

Although both plants and animals have been flown, an adequate data base has not yet been obtained. There are several reasons for this. First, the opportunities for flight have been rare. Second, the environment provided for living material in spaceflight has not been optimal. The threshold of gravity-sensing systems in plants and animals is unknown, but there is reason to believe that it is between 10^{-5} and

10^{-6} g in certain organisms. It has been calculated and demonstrated in flight that sedimentation and convection are no longer operative at these g-levels. These twophysical factors are believed to be the principal phenomena affecting the gravitational input within the cell. Spacecraft to date have not provided this g-level. Continuing flight of the Space Shuttle will provide limited opportunity to expose living systems to microgravity, but it appears that the opportunity to do the critical experiments must wait for the development of facilities providing both lower g-levels (10^{-5} to 10^{-6} g) and flight times of months to years. A module, if mounted at the center of mass of the Space Station and not perturbed by human or machine activity, could provide a suitable environment. Special damping procedures may also be needed to isolate specific items of experimental equipment. Otherwise, a free-flyer or platform may be required.

In addition, an onboard centrifuge is needed, capable of accommodating animal and plant material, and perhaps even human subjects. This centrifuge would provide a 1 g control for microgravity experiments, as well as the capability to explore a range of g-levels between 10^{-5} and 1, and thereby study thresholds.

<u>**Artificial Gravity**</u>. The Space Station is an ideal environment in which to study various issues related to the use of artificial gravity, and to recondition crews from long-duration manned missions using an onboard variable gravity human centrifuge. First, from a practical point of view, little is known about how much (and for how long) gravity is necessary to counteract the known effects of weightlessness on the human organism. The Soviets have done a fair amount of work using centrifuges on their spacecraft, and have claimed that most of the deleterious effects of spaceflight (at least on rats) have been either prevented completely by artificial gravity or significantly reduced. These claims need to be substantiated by us under carefully controlled conditions. While a fraction of this research, particularly with humans, can be done on the ground (e.g., studies on coriolis effects), the Space Station is ideally suited for determining the g-level that would allow humans to operate for long periods of time without deleterious effects such as cardiovascular deconditioning, muscle atrophy, and bone demineralization. A program is needed utilizing both animals and humans over an extended period of time to determine if man can be exposed to microgravity for a year or more or whether continuous or intermittent gravity is necessary. In a similar vein, there are currently many problems associated with the future use of plants, algae, and other

organisms in closed life support systems, for which we will need to determine the optimum gravity regime for their continuous cultivation. For studies of this type, we cannot now specify the nature and sequence of studies that will be required, but we feel absolutely certain that they will have to be done. We feel that NASA should develop plans along these lines too.

Another aspect of artificial gravity for which the Space Station will be extremely important has to do with possible bases on the Moon or on Mars. We know, from the Apollo missions, that humans did not seem to show any substantial physiological deviations after a sojourn of a few days on the Moon at 1/6 g . Can we extrapolate from these findings to the situation where people may have to spend weeks or months at 1/6 g, or in the case of Mars at 2/5 g? Is this consistent with their long-term health and well-being? Will their bones decalcify under these circumstances? Experiments should be performed at 1/6 or 2/5 g using an onboard centrifuge, a tethered satellite, or a spinning spacecraft.

Platforms. Life sciences has a very real interest in co-orbiting platforms as well as polar platforms. For the field of exobiology, we see four potential uses of platforms.

(1) **Collection of cosmic particles.** Quite apart from the needs of other disciplines that may be interested in the collection of cosmic dust, we are particularly interested in the biogenic elements and in the organic compounds that may be present in this material. In principle, non-destructive methods of collection are possible, and these could give extremely useful information about the organic components of these particles. Even if these methods cannot be developed, we are still interested in the elemental, and if possible, isotopic composition of these materials. For experiments of this type, we can probably be accommodated best on platforms where relatively large collection areas can be devoted to this purpose, and where contamination from the outgassing Space Station will be minimized.

(2) **Conducting in situ experiments.** A number of different investigations of this type are of potential interest to biologists. First, their investigators will want to expose either living material or chemicals to the environment of space. Some are interested in radiation, others in a hard vacuum, still others in the combined

natural environment of space. Since there is interest in the issue of "panspermia," there are experiments requiring exposure of living materials to the space environment to study survival. Such experiments could be set up on either platforms or smaller free-flyers.

For investigators who want to study aspects of cometary chemistry and structure, such experiments would probably best be carried out within or near laboratory modules, although it may be possible that some of these studies can be accommodated on a platform equipped with suitable analytical equipment.

(3) **Earth observations.** It is clear that platforms, particularly polar platforms, would be desirable for studies in global biology to seek out large-scale phenomena associated with marine and terrestrial biota, as well as to study aspects of the global cycling of key elements and compounds through the atmosphere and the biosphere.

(4) **Astronomical observations.** Important astronomical observations in all regions of the electromagnetic spectrum are of great interest to the biological community. Clearly, the major impetus for these studies will come from the astrophysics and planetary communities. But the planning for platform-borne facilities such as SIRTF, AXAF, and LDR should accommodate the needs of our community, which is vitally interested in the composition of interstellar clouds (particularly organic compounds), the composition of the atmospheres of solar system objects, the possible formation of other solar systems, and the fate of biogenic elements in evolved stars in other galaxies. Finally, platforms could also be used to search for extraterrestrial intelligence.

<u>Constrained Missions</u>. The life sciences discipline, along with materials science, will be a major user of the Space Station complex. Obviously, the smaller the volume of space for experimentation, the lower the scientific return. This axiom is doubly important for life sciences. Any reductions in the number of crewmembers, crew availability, and laboratory space all directly impact our research capability. A "man-tended" Space Station seems to defeat the major objective of extending human presence in space. While a reduction in the number of modules could be mandated by cost, there must be sufficient space for crew habitability, medical care, and monitoring, and there should be discrete space for scientific research in the life

sciences. A man-tended module does not do that and is not acceptable. Life sciences research must begin with IOC and grow from there. The entire Space Station concept is ultimately dependent on the life science research program, in that human presence is an integral part of the concept. Humans must work effectively and safely from the initial stages of construction of the Space Station. The productivity of all the other sciences will depend on the performance of humans in space from the onset of the Space Station era.

2.6 MICROGRAVITY

The topics of microgravity science and application, and physics and chemistry in space are combined here because these disciplines share common requirements for very low steady state acceleration (g) levels and very low vibration levels aboard the Space Station. Therefore, we have devoted special attention to strategies for achieving these conditions in one or more of the experiment modules. In addition, evolution of the Space Station beyond IOC is considered because of the impact such capabilities will have on the IOC design.

The Microgravity Environment Aboard the Space Station

Quasi-Steady State g-Levels. The steady state g-levels required on the Space Station will vary by orders of magnitude from one class of experiments to another. For example, meaningful low-gravity experiments on glasses and ceramics can be effectively run at levels as high as 10^{-3} g, yet such experiments can profitably use an en-vironment of 10^{-5} g. Surveys of stated requirements show clustering of experiments in various fields requiring 10^{-5} g. However, this clustering may be due to the fact that many responses to these surveys came at a time when 10^{-5} g was generally thought to be the lower limit to the g-level that might be available. We believe that for many of these experiments, 10^{-5} g is marginal and that 10^{-6} g would be a much more suitable target for making the experiments meaningful. These experiments are in such fields as combustion, electronic materials, metal processing and solidifications, biotechnology, and fluid dynamics.

There are still other important experiments on critical phenomena and on quantum fluids, for example, which will require g-levels in the range of 10^{-7} to 10^{-9} g. Finally, certain experiments in gravitational physics will require environments of 10^{-9} to 10^{-10} g.

We therefore recommend that the Space Station be designed to provide one or more microgravity modules at IOC whose steady state g-level does not exceed 10^{-6} g while experiments are in progress.

Pursuant to the above recommendation, we strongly support a configuration for the Space Station in which the experimental modules are clustered along the flight path of the center of mass of the Space Station, keeping as much of the experimental volume as possible within the 10^{-6} g elliptical tube. We hasten to point out that such a configuration can provide g-levels below 10^{-6} g throughout most of the module volume, not just at a choice location, and that it will permit the addition of more modules of similar quality such as those proposed by the Japanese, ESA, and commercial users.

Time Dependent Accelerations. Experiments aboard the microgravity module will be sensitive to vibrations and excursions caused by crew activity, Shuttle berthing, Orbital Maneuvering Vehicle (OMV) docking, onboard machinery, flexing of the Space Station structure, etc. As long as the disturbance frequencies are above 0.3 Hz and the amplitudes are below 1 cm, these vibrations may be filtered out by shock mounting the experiments; active feedback isolation systems may be required. It is anticipated that some individual experiments will be designed to provide their own isolation system, while others will share common isolation systems. Space should be allocated for isolation tables provided by the Space Station and those in the experiment packages. In addition, provision should be made for the servo positioning of any attached connections to the experiment so as to provide zero net momentum transfer. In general, accommodation of vibration isolation schemes, whether at bench, rack, or module level, is a systems engineering function.

The characteristic size of most experiments is on the order of 1 m or less, indicating that frequencies below 500 Hz or so will act as if they are in the low-frequency limit, uniformly accelerating the payload. If a dissipative acceleration effect exists (i.e., friction or viscosity), the vibration is in effect rectified. Additional problems can be encountered with experiments that are intrinsically microphonic, such as gravity gradient accelerometer packages.

Monitoring g-Level. To be useful for microgravity experimentation, the Space Station inertial acceleration environment must be fully characterized. Three linear and three angular accelerations must be measured at several positions around the center of mass. The measurements should cover a frequency range of 10^{-3} to 10^{3} H_z and be archived at some acceptable sampling rate for later use as well as made available in real time. Real-time displays of acceleration amplitude and direction should be available in various locations in the module. Annunciators should serve as indicators for personnel working on board so that unnecessary momentum disturbances can be minimized during critical experiments.

Sub-micro-g Acceleration Levels. The Space Station can help make possible g-levels in the range of 10^{-7} to 10^{-11} g. Such experiments could be accommodated on platforms or free-flyers based at the Space Station. Factors that will tend to limit the design of experiments include the small volumes over which such g-levels can be obtained and self gravity.

Gravity levels below 10^{-10} g are best obtained by using drag-free satellites, a technology that is now in place and being used. Its use for experimental physics presently is very limited because each experiment requires its own satellite. The Space Station can change this situation dramatically by having the capability of servicing such drag-free satellites, supplying propellants and cryogens, and by changing out the experiments as required. The Space Station should also have the capability of testing out the experiments before transferring to a drag-free system.

A possible strategy for obtaining g-levels below 10^{-6} g might be to use an un-pressurized volume as an orbiting drop tower, allowing the experimental package to follow a geodesic path in the tower. The analogy to earth-based, short-duration, low-g facilities that are used extensively today is obvious. It is estimated that g-levels on the order of 10^{-8} to 10^{-9} g could be obtained in this way for periods up to one hour. Such times are adequate for many experiments. The initial position and velocity of the package are important factors limiting the duration of undisturbed motion in the tower. The drop tower could simply be an unpressurized Space Station module, or perhaps an external tank connected to the Space Station through an airlock. The tower would need to fly along the flight path of the center of mass of the Space Station.

Evolution Beyond IOC

Even at this early stage in planning for the Space Station, it is essential that NASA examine the activities that are anticipated over the 25- to 30-year operational life of the Space Station. Such activities can be implemented only if growth of the Space Station is allowed by the initial design. Those activities that must be considered first are the items that were deferred at IOC, particularly additional pressurized module payloads. When it becomes necessary to remove equipment from the experiment modules, storage space must be made available so that it will not be necessary to return all unused hardware to the ground. Additional modules may be available from not only the current NASA and international programs, but also from commercial space services. In order to plan such expansion, a growth model should be constructed based on past program growth rates. For example, at a growth rate of 5 percent per year, an expansion in terms of volume and mass of about 150 percent should be planned for the end-of-life Space Station.

Attached payloads have been deemphasized in the U.S. program, but are an important part of the initial European program. However, even in the U.S. program, we expect an increasing use of the attached payload capability as experience is acquired over the first few years. It is important to remember that not only space will be required, but also remote robotic access for hardware installation and servicing, and for specimen insertion and retrieval. Attached payloads will also require the same microgravity environment as the pressurized module payloads.

Other important evolutionary changes in microgravity activities include co-orbiting platforms, a flying drop tower, and tethers for variable gravity capability. We anticipate that co-orbiting platforms increasingly will be used for payloads requiring long quiescent times, such as crystal growth. These platforms must be standardized and modularized so that one bus can be used and reused. Naturally, servicing of these platforms will be an increasingly important function of the Space Station. The flying drop tower is a simple onboard capability discussed previously that would enable experiments requiring less than 10^{-6} g. Tethers will provide opportunities for small experiments that require constant, controlled acceleration levels. Although there are no current requirements here, we anticipate that there will be interest in the future. Therefore, any plans to use tethers for applications, such as plasma physics experiments, should also consider the possibility of small attached micro-gravity payloads.

Beyond the currently identified activities lie a set of possible opportunities related to our evolving view of outer space as an environment for human existence and continuing exploration. In this respect, the Space Station is the first transportation and construction node in a series of increasingly larger and more complex endeavors. Therefore, it is useful to examine projects that will support the development of future capabilities in space. Some possible advanced technology development projects are new automated space propulsion systems, new composite construction materials and assembly techniques, automated propellant production manufacturing methods using extraterrestrial materials, and use of these unique materials for construction and as radiation shielding for manned missions into deep space. Such future directions will stimulate interest in planetary materials science and engineering and in using Space Station capabilities to identify and develop the required technologies.

In considering evolution of the Space Station, it is useful to examine also the perceived growth limits of such capabilities as transportation systems, communications, volume, and power. Such examinations may provide insight into the basic question of whether the future evolution will emphasize replication of the Space Station or the continued growth of a single structure. One evolutionary option might include the provision of a second structural element at a lower altitude to serve as a more convenient transportation node. Viewing for space and Earth observation will require three-dimensional expansion options that minimize interference of the future additions to the IOC structure. Contamination is a serious threat to those sciences requiring remote observations. Serious consideration should be given to the active management of all contaminants as opposed to using overboard dumps, as has been the past practice. Both viewing and contamination constraints may provide increased pressure to consider separate structures for evolution beyond IOC. In the transportation area, there is concern over the viability and availability of the current complement of orbiters in the STS fleet over the next 10 to 20 years, especially since there are no current plans to continue the development of Shuttle-type systems or to use expendable launch vehicles for servicing. In the communication area, the limitations of the current Tracking and Data Relay Satellite System (TDRSS) are well known; however, NASA has not announced any plans to relieve them. Serious consideration should be given to the addition of 20/30 GHz satellite support during the lifetime of the Space Station. The microgravity volume has been discussed extensively. Growth along the flight path of the Space Station cannot continue without limit, so other accommodation schemes should be considered. Power is always going to be a limitation in the Space Station. The technology used to provide power at levels of under 100 kW may be substantially different from that required for levels approaching 1 MW, which will almost certainly be required by 2020. Therefore, accommodation of additional power sources that are not necessarily coupled to the Space Station should be considered seriously for possible impact to the IOC design.

3.0 REPORTS OF THE PAN-DISCIPLINE TEAMS

Four Pan-Discipline Teams met at the summer study. The Configuration, Platforms, and Communications and Information Systems Teams were continuations of efforts established the previous summer. The fourth team was chartered to consider Science Operations. All summer study participants were able to contribute to the Pan-Discipline Teams because separate meeting times were assigned to the two types of teams. The issues discussed in the Pan-Discipline Teams were strongly influenced by pending decisions in the Reference Update Review (RUR) process. The first of the three planned RUR's had been completed prior to the summer study. However, the more difficult and controversial decisions were scheduled for consideration later. This made it possible for the Pan-Discipline Teams to become familiar with some of the design trade studies that NASA and the foreign partners had initiated. Key staff members from the NASA and foreign Space Station Program Offices were present to answer questions and listen to what can only be described as lively discussions of those topics that were of interest to science and applications users.

3.1 CONFIGURATION

The Pan-Discipline Team on Configuration has formulated a substantial number of recommendations. Most are motivated by one of the many decisions that the Space Station Program is scheduled to make within the next few months. Because of an indication from NASA representatives that cost constraints may well limit the initial capability, statements of general priorities from a science standpoint are an extremely important part of our recommendations. The specific recommendations of the Configuration Team are as follows:

(1) Module length (or volume) is the most important single design parameter enabling productive laboratory science.

Module volume is important both at the IOC and for growth beyond that time. The longest modules possible should be launched even if substantial outfitting is required on orbit. The Shuttle lift weight will determine how much outfitting is done before launch. The alternative is a shorter module that can be launched fully outfitted. In fact, some empty volume is thought to be advantageous, because it will permit stowage of experiments for later use and more convenient installation of new experiments. It will also make room available for some "small, quick" experiments, analogous to the suitcase or stowage locker experiments possible on the Shuttle. An extensible or telescoping module has been proposed and may be worth some study as a way to have larger volumes in orbit than at launch.

(2) Interconnect nodes should be used at the junctions between modules.

The concept of interconnect nodes is very important and has the endorsement of the TFSUSS principally because of the extra volume that can be saved for experimental work within the pressurized modules. The nodes (say 3 m cubes, with up to six faces available) can be used as EVA and hardware transfer airlocks, and as docking ports. They could have windows for photography or be used for storage. Without interconnect nodes, these functions would have to be provided in the modules, further constraining the volume available for research or habitation. It should be noted that only two long modules with interconnect nodes will contain more useful experiment volume than the present four, smaller modules in the Reference Configuration.

(3) Combining laboratory and habitability functions in a single module has substantial advantages and ensures flexibility.

The Space Station Reference Configuration has four U.S. modules. Two are used as laboratories and two as living quarters. The TFSUSS prefers an alternative concept with both functions being incorporated into each of two lab/hab modules. In this way, growth can be made one module at a time, which is especially important with longer modules. Because some of the laboratory outfitting may be done on orbit, it seems assured that the design will be flexible, allowing variations in the lab/hab percentages as the Space Station evolves. For the lab/hab option, the design verification and some manned science will be possible with launch of the very first module. This is especially important in the case of a stretched out initial phase. Also, suitable safe haven accommodations are automatically provided with only two lab/hab modules. The lab/hab design will require careful attention with regard to hazardous operations and the avoidance of interdiscipline conflicts.

(4) Each module should be equipped for at least six crewmembers.

This recommendation deserves high priority, as well, especially in the case of long, lab/hab modules. Assuming that most of the utilities (environmental control, electrical power, data management) will be installed prelaunch, it is essential that they be sized to accommodate the work of six people. In addition, the other habitation functions, especially the sleeping quarters, galley, and waste management systems, must also be sized for six people in each lab/hab module. This will allow an adequately sized crew to initiate significant experimental work with only one module, plus international laboratories. It will facilitate completion of the IOC Space Station as rapidly as possible. Upon arrival of the second lab/hab module, the crew size can be expanded to undertake truly ambitious experimental work.

If cost constraints should require a "man-tended approach" (MTA) for some period, the lab/hab configuration can place automated science first, yet permit relatively easy growth by installation of the appropriate habitability features.

(5) International participation in Space Station is essential.

Next, the importance of international participation needs to be stressed, especially in the presence of cost constraints. In addition to the basic module contributions considered by ESA (Columbus) and Japan (JEM), and the Canadian Servicing Facilities, a number of other possibilities should be examined. The science community has much experience in working with our international colleagues and we are confident that satisfactory operational arrangements can be made.

An ESA Logistics Module could replace the U.S. version. The ESA module would probably be based on Spacelab technology. It does not need elaborate outfitting, but can be basically a container/carrier.

A number of small platforms have been proposed and early versions have already flown. These include the European Eureca and U.S. Spartan. Their further development is encouraged.

A small (few kg), rapid, sample return capability has been suggested informally by several Europeans with possible significant cost savings due to the reduced need for sample preparation and characterization on the Space Station.

(6) Modules should be as near the center of gravity (CG) as possible.

An overall configuration that permits reasonable volumes to be located near the flight path of the CG seems important. The current Reference Configuration, the "power tower," places the modules well below the CG. Thus, there is a substantial gravity-gradient acceleration (about 10^{-5} g) in all laboratory areas. Vertical displacements of less then 3 m from the CG are required to keep gravity-gradient accelerations below 10^{-6} g. Even if not needed at IOC, a growth into the need for this low acceleration level is expected.

(7) The module operating environment should be one standard atmosphere.

This environment (14.7 lbs per square inch, 21 percent oxygen) is recommended to avoid uncertainty in comparison with ground controls (see Section 2.5). The alternative is a lower pressure and possibly a higher oxygen fraction. The alternatvie reduces the "prebreathing" time required to avoid possible "bends" symptoms during EVA. Although a lower module pressure would make preparation for EVA more efficient, less tedious, and less time consuming, this would lead to many other design problems and complications. Materials flammability is increased at lower pressures and with enriched oxygen, reduced convective cooling will be available at lower pressures with more reliance on cold plates of higher volume air cooling loops. We expect a lower module pressure to severely impact scientific hardware selection and qualification.

Since there are other options available for EVA preparation, such as portable masks or reduced pressures overnight in an interconnect mode, we recommend pursuit of such an alternative.

(8) The "man-tended approach" does not serve science well.

A "man-tended approach" (MTA) is being studied at the request of Congress. MTA is an evolutionary step providing automated science capabilities prior to continuous man presence, if required by cost constraints. Many disciplines, especially microgravity, life sciences, and solar-terrestrial physics plan to make heavy and continuous use of the crew. Therefore, the concept of MTA does <u>not</u> serve the needs of these science communities well. The servicing of co-orbiting platforms and free-flyers would probably be transferred to the Shuttle. Cost savings in operations could presumably be made, but at a severe loss of manned science capability.

(9) An Extended Duration Orbiter (EDO) should be developed immediately.

The need for an extended flight duration capability was listed last year as an important recommendation. Nothing appears to have been done since then, yet the case is now more compelling than ever. NASA is spending several hundred million dollars every year on Spacelab flights of 7 to 10 days duration. The useful science operations interval (5 to 8 days) can be more than doubled with a 16-day orbiter flight duration. All of these missions are important not only for science merit of their individual experiments, but also as a testbed for many Space Station payloads and operations concepts. Cost estimates of $25M to $100M, depending on assumptions, all appear very cost effective from a science standpoint. We emphasize again the necessity to pursue this opportunity vigorously.

(10) The Space Station architecture should be flexible and modular.

We also note that some architectural options incorporate flexible, modular construction techniques. Not only habitation functions like showers or sleeping quarters may be moved, but full equipment racks and even functions themselves may be exchanged. This flexibility seems very commendable and a very important part of ensuring adequate growth capability for the Space Station.

3.2 PLATFORMS

The proposed Space Station consists of four basic elements. The most widely discussed element is the manned base; in fact, there is a tendency to think of this element as "the Space Station." However, there are three other elements, viz., an OMV and two platforms, which are integral and very important components of the Space Station Program.

Prior to discussing the deliberations and recommendations of the Platform Team at the 1985 TFSUSS summer study, it is useful to review the history of this topic since the formation of the TFSUSS. The concept of Space Station platforms set out by

NASA was one of a relatively large structure derived in the main from subsystems of the manned base. As initially conceived, platforms are provided as part of the IOC Space Station. One of these, the "co-orbital platform," was designated as an astro platform. The other was designated as the "polar platform." The instrument complement on the co-orbital platform was to consist of a mix of facility-class telescopes, notably AXAF and SIRTF, along with other presumably smaller payloads. The polar platform was intended for use by the EOS.

The initial response of the TFSUSS to this concept of Space Station platforms was strongly negative for a variety of reasons. The astronomy/astrophysics community did not want a multi-instrument platform because of fundamental incompatibility of the major observatories, AXAF and SIRTF, with each other. This incompatibility arises from both a contamination and an operational point of view. The latter refers to physical disturbances associated with the use of either observatory on the other, as well as to different optimal orbits for AXAF and SIRTF. Concern from the Earth observations community was also expressed about the polar platform from the standpoint that the scientific return would be compromised if only one system was available because of a need for more than one equatorial crossing time. A morning and an afternoon crossing time are considered necessary for optimal scientific return. However, the concept of a multi-instrument platform is acceptable, indeed desired, for the Earth Observations community. A general concern was raised about the size of the proposed platforms. In particular, it was felt that if a large platform or platforms were provided, there would be pressure by NASA to use the facilities even if they were not optimal for the conduct of science. Also, there was concern that the large size precludes the use of small, simple, and, therefore, less costly scientific instruments.

These discipline-specific and general concerns about the platform concept led the TFSUSS to recommend that NASA consider a modular type of platform, one whose basic components were not necessarily derived form subsystems of the large manned base, and which, through its modular character, could accommodate individual facility-class instruments such as AXAF or SIRTF, as well as multiple instrument payloads such as the EOS. The TFSUSS also strongly advocated that consideration be given to a smaller class of free-flyers to be associated with the Space Station (e.g., a Space Station Spartan or a modified Eureca).

Although this point of view was expressed early in TFSUSS's deliberations, there was no immediate sign that it was being considered in the platform studies. This situation changed a few months into the Phase B studies, and prior to this summer study, when the Associate Administrator for Space Station directed the Phase B contractors to study this concept. The TFSUSS wishes to acknowledge this action as one of many indications that the Space Station Program is being responsive to the concerns of the user community.

In light of the tremendous scientific potential associated with Space Station platforms, and the move to include a modular concept in the platform trade studies, emphasis in the 1985 TFSUSS summer study was placed on a critique of the modular concepts, a review of potential discipline utilization of platforms, small "platforms," international involvement, and geosynchronous platforms. Although these topics were the principal ones discussed by the Platform Team, a number of other issues were also considered.

The Modular Platform Concept

A major focus for the Platform Team was a critique of the modular platform concept currently being examined by the Goddard Space Flight Center and its contractors in response to the request by the Associate Administrator for Space Station. This modular approach, taken in its extreme form, presumes that a user (which is likened to, and may actually be, a Project Office at a NASA Center) is responsible for providing the physical structure and systems engineering necessary for a given platform mission. It is anticipated that the actual physical integration of the modular systems with the user-provided structure/payload could be accomplished on orbit. It was felt that the compelling advantage of modularity is that it allows maximum generality in user accommodations; servicing, maintenance, and repair; instrument replacement; and platform evolution.

Modularity can include all those resources that need not be truly mission-specific, and those resources should be sized to accommodate instruments/facilities either singly or in simple multiples. It was felt that sensible examples of systems that could be viewed as likely users of Space Station platforms (e.g., AXAF, EOS, SIRTF, and STO) should be used to provide a quantitative sizing of module capability. In particular, the Team identified the following module characteristics:

- Platform power should be derived from multiples of a basic module capable of delivering 2 kW.

- Command and data handling should utilize a standard command unit, one compatible with that developed for use on the manned base of the Space Station, and provide standard data packets at transfer rates that are multiples of 64 kbps.

- The attitude control system should provide 0.1 arc second performance for payloads masses up to 4500 kg distributed over a linear dimension of as much as 15 m.

It was felt that a modular approach offers distinct advantages to a wide range of user communities, both at IOC and in the evolutionary era of the Space Station. It should be stressed that this view was held by all of the institutional and discipline representatives involved in the Platform Team.

> **In summary, the Platform Team strongly endorses the modular platform concept being developed by Goddard over the single unit concept that was initially suggested by the Space Station Program.**

<u>Potential Users of Space Station Platforms</u>

At the time of the 1984 TFSUSS summer study, two scientific communities were considered as users of Space Station Platforms, viz., astronomy/astrophysics on the co-orbiting platform, and Earth observations on the polar platform. One of the major topics for consideration by the Platform Team during the 1985 TFSUSS summer study was a reexamination of possible scientific utilization of Space Station platforms.

It was abundantly clear that there is a growing appreciation in a variety of scientific communities of the value of Space Station platforms. Affirmation of the great potential of platforms for the astronomy and astrophysics, as well as for Earth observations, was evident in the discussions. The Platform Team also heard an excellent discussion of the role of platforms in the planning of National Oceanic and Atmospheric Administration (NOAA); in fact, NOAA is currently negotiating with both NASA and ESA to share in platform utilization. Another community that could benefit in a significant way from use of a Space Station platform is that involved in solar-terrestrial research. It should be stressed that the scientific requirements of the solar-terrestrial community necessitate a platform that is not in a sun-synchronous orbit. This constitutes a basic conflict with the sun-synchronous orbits needed for the EOS/NOAA systems.

It is not surprising that the scientific disciplines mentioned above could benefit from Space Station platforms. However, there was also interest expressed by three other disciplines. The microgravity team is interested in platforms because of the potential for even lower acceleration levels than are possible on the manned base. This interest is most evident after IOC when it is expected that the material science community will have learned from its opportunities on the manned base. Interest in platforms was also expressed by the life sciences community. This interest took several forms. One involved a variety of research efforts in exobiology including cosmic dust collection, in situ experiments on organic chemical evolution, and observational studies for the presence of organic compounds in the cosmos as well as for the presence of extraterrestrial intelligence. Also mentioned were studies of basic biological phenomena in very low-gravity environments, and the use of a platform as a long-term animal holding facility in the post-IOC era. The physics and chemistry team has also recognized the potential of platforms for their discipline, identifying the possibility of low acceleration man-tended research facilities, as well as the possibility of developing platforms for study of both basic plasma physics experiments as well as of space plasma processes.

> **The value of Space Station platforms, with their modular characteristics, to a wide range of scientific disciplines is extremely high. It is becoming clear that the Space Station platform can herald the next step in the evolution of free-flyers to the greater benefit of science in space.**

Small "Platforms"

The Platform Team reexamined an issue that was raised by the TFSUSS during its 1984 summer study; the need for and role of small free-flyers associated with the Space Station.

These small "platforms" are operationally perceived to be systems that are too small to serve as carriers for facility-class systems such as AXAF or SIRTF, and therefore are not viewed by the TFSUSS as part of the Space Station provided hardware. Analogs of these small systems are the NASA Spartans and the ESA Eureca systems.

It was the position of the TFSUSS following the 1984 summer study that this class of small free-flyers could play a very valuable role in the conduct of science in space, facilitating users from virtually all of the space science disciplines. The Platform Team heard discussions on upgraded versions of both the Spartan and the Eureca concept, versions that would be designed to optimize their use and flexibility in the Space Station era. A significant aspect of this class of system is that it affords, in principle, relatively easy and quick access to space experimentation/observation by small groups such as university teams composed of a professor and graduate students. These systems provide the "quick is beautiful" science opportunities for free-flyers.

It was clear that the need for this type of capability extends to a variety of orbits, including those of high inclination as well as those of low inclination. The need for the former arises primarily from a requirement to deviate from a sun-synchronous orbit, and from a nadir pointing attitude.

> **The Platform Team felt that a Eureca derivative and/or a modified Spartan concept would well serve the needs of those desiring this type of free-flyer. We therefore strongly support the conclusion of the 1984 summer study that Space Station should provide servicing and operational accommodation for this class of free-flyer. In addition, we recommend further study of whether these small platforms should be reusable, or whether they should be "throw away" systems. The cost benefits of reusing small systems have not been demonstrated in a convincing manner.**

<u>International Involvement</u>

Space Station platforms offer tremendous potential to a variety of international science communities. Therefore, the Platform Team felt that it is important that early, discipline oriented, and detailed consultation occur between likely platform user groups. This was viewed as being particularly important in accounting for the requirements of research, operational, and commercial users, both U.S. and international, in selecting payloads on the proposed system of polar platforms to be used for Earth observations.

Geosynchronous Platforms

At the request of the Associate Administrator for NASA's Office of Space Science and Applications, the Platform Team examined the level of interest in Space Station platforms operating at geosynchronous orbit. While this request was motivated principally by an interest in communications systems on such platforms, it soon became apparent that there exists an equally compelling interest in a number of space science communities for platforms in this orbit.

> **It is significant that all potential users of a platform at geosynchronous orbit, including the communications community, felt that the basic modular platform concept that has been advocated for Space Station platforms at IOC would also well serve the needs of geosynchronous platforms. The Platform Team therefore endorses an interest in geosynchronous platforms as part of the post-IOC era of Space Station.**

It should be noted, however, that further consideration needs to be given to the relative priority of this effort in comparison with development of additional platforms at lower altitudes, as well as with the development of a greater variety of attached payloads and additional payloads within Space Station laboratory modules. This is particularly important in light of one of the key attributes of Space Station platforms and the associated high priority given to that attribute, viz., on-orbit servicing. Until an OTV is developed, there can be no servicing of geosynchronous platforms.

Additional Considerations

Although the issues discussed above were the central focus of the Platform Team considerations during the summer study, a variety of other issues were also discussed including platform servicing, and time phasing of platform activities with respect to activities associated with the manned base of the IOC Space Station. Two of these other issues deserve special mention.

Present guidelines to Space Station platform studies with regard to the lift capability of the Space Transportation System (STS), particularly to polar orbit, are presenting major limitations to those studies, particularly for the polar platforms. In light of the fact that a higher level of performance involving STS engines operating at 109 percent thrust and filament-wound solid motor cases has been offered to the military, we find this constraint on the civilian program to be artificial and potentially damaging. We therefore strongly recommend that the Space Station Program and its users work together to secure the same level of performance from STS that has been granted to military. It is important that this be done at the earliest possible time. It would seem that access to a greater lift capability would also be of great benefit in the assembly of Space Station elements in low inclination orbits.

Finally, we wish to record our concern that should the Space Station Program find that its estimates of the cost of providing a Space Station are too low, that it not eliminate either of the two platforms as a means of reducing cost. There is a clear demand for three or more platforms at IOC when one considers research, and operational and international users.

> **In view of the wide variety of users associated with Space Station platforms and the fact that the total cost for this important Space Station element is a small percentage of the total cost for the Space Station, we strongly urge NASA to remain fast in its promise to provide two platforms at IOC.**

3.3 OPERATIONS

This section focuses on Space Station operations. It is almost impossible to separate the science operations concepts from the communications information systems issues, since the science operations concept depends heavily on voice, video, and data communications between the Space Station and the ground observers. For that reason, the early sessions of the Science Operations Team were conducted jointly with the Communications and Information Systems (CIS) Team.

This section contains recommendations on the communications and data systems on the Space Station, on the operations philosophy, and on issues such as crew size, equipment certification, integration concepts, and the nature of science support aboard the Space Station. Although deemed very important, there was not enough time during the summer study to address the vital issues of prioritization, how experiments are selected for flight on the Space Station, and how resources are shared and decisions made. These issues will continue to be addressed in the coming years by both the TFSUSS and NASA . The important recommendations are followed by backup material and then finally suggestions of future work. It is worth noting that the general philosophies of science operations that have been generated inside NASA are very close to those concepts advocated by the science user communities. There is the realization by NASA and also the user community that the Space Station must be responsive to the user. It is no longer a program in which the object is to get into space and get back safely, but a program that must be responsive to the user community, be that the science, commercial, or other communities. The members of TFSUSS are very heartened by this outlook and want to commend NASA management for their initial Space Station and science operations concepts.

The committee endorsed the concept of "telescience," which seeks to use both onboard and ground resources to optimize science return. The concept of telescience does not apply exclusively to space operations, in fact, there are many examples of ground-based researchers who are not in physical contact with their equipment. Telescience applies equally to these situations, and the knowledge and techniques that can be developed for the space program can be applied to this ground-based research. Telescience implies that the major computer power is on the ground for detailed data analysis, that scientists are in direct contact with their instruments and crew when an experiment is being conducted, that the use of onboard resources is reserved for those functions that cannot be done on the ground, and that there is a very high flow of information to and from the station.

The specific recommendations of the Science Operations Team are as follows:

(1) Develop a mechanism to insure close user involvement in the design of the operations philosophy including the operational verification phase.

It is important to bring the users in early in the decision making process. This is already happening with the formation of the TFSUSS Science Operations Team. It is very important that the transition from operational checkout to routine science operations involve the user. We envision a 1-year period where the primary activities are construction and checkout. Experiments would be conducted, because this is the best way to verify that the station can, in fact, support the users and conduct experiments. The scientists realize, however, that during this checkout phase, science experiments will be secondary objectives.

(2) Develop a mechanism for the management of user-allocated resources.

We suggest that the allocation of resources for the entire user community should be governed by a panel of users. This will not be easy to do since there will be more than one class of user (OSSA, commercial, international, etc.). Since this is a long-term project, it will be impossible to keep a "marching army" of supporting people on the ground to keep track of resource usage, allocation, and planning during the entire duration of the Space Station. We considered the concept of an expert system continuously monitoring and controlling resources, both for ground planning and on-orbit operations. However, we decided that a better technique was to schedule sufficient margin into resource allocations to give schedule flexibility, allow adaptive and iterative experiments, and to reduce the effort for resource tracking. It will be very important, however, to have some form of a value-accounting system to provide an incentive to stay within one's allocation, to be frugal with the resources, and finally, to be able to do accounting of the resources by experiment. We must point out that the systems operation must also do the same type of accounting and be responsible to the users to avoid overrunning their budget. We feel strongly that any changes in availability of resources to the users should not be a one-sided affair with the system dictating its demands to the user. For example, if it becomes necessary to do a reboost several days earlier than programmed, there should be user input into that decision and, in fact, unless a dire emergency occurs, possibly even a veto if warranted.

We recommend that NASA begin to testbed resource allocation scenarios in conjunction with the formation of a university-based consortium to evaluate Space Station science operations. These testbed concepts could take the form of laboratories that initially utilize commercial or NASA-sponsored electronic communication to judge the effectiveness of various forms of communication. For example, in a given type of experiment, is real-time (30 frames per second) video needed or can one use a slow-scan? Perhaps a high-resolution system is needed, although this imposes a far larger bandwidth requirement. In another area, is teleoperation feasible or must a person be there to perform manual operations? How much computer control is needed? How long must the investigator be present during the conduct of the experiment? Must one have real-time voice communication? How do you sense and regulate resources? All of these questions can start to be answered by establishing and using this consortium. As the design of the Space Station systems matures, it will be possible to evaluate parts of them using this consortium, especially in the CIS area. This evaluation could proceed in parallel with the design reviews so that some experience could be obtained and make the requirements more realistic.

We recommend that operations concepts be tried on the shuttle during already planned experiments (especially during Spacelab missions). These might involve, but not be limited to, remote science payload operations centers, increased use of downlink video (possible slow-scan or high-resolution), the evaluation of uplink video, and the evaluation of new uses for computer technology (speech recognition, speech synthesis, expert systems, and automation).

(3) We recommend that NASA relax equipment and operations constraints.

In order to make the Space Station environment more like that of ground-based laboratories, we strongly recommend that commercial equipment be used for payload operations, and subject to some minor constraints, be approved for flight aboard the Shuttle. Further, we recommend a partition, either physical or functional, between the station system areas and the payload/laboratory areas. This partition would allow more hazardous activities to be conducted in the laboratory areas, such as use of lower reliability equipment, toxic materials in hoods, unverified procedures and interfaces, machining and construction operations, and other types of activities that have heretofore not been allowed on manned spacecraft. These operations obviously have to be conducted with little or no interference or hazard to Space Station system operations. Consonant with the above recommendation, we recognize that safety is vital and do not imply that we support unsafe operations, but rather that there are a class of activities that could be hazardous if mistreated and that these activities, performed routinely on Earth, could and should be conducted in space.

In addition, the concept of on-orbit integration should become standard operating procedure as many experiments will be revamped, new equipment added, and old equipment made to function and interact in new ways. This concept includes the notion of packaging equipment in protective wrapping for transport so that the launch vibration constraints can be solved easily and cheaply. Also, an onboard stockroom and workshop will be needed to support this on-orbit integration and renovation. Concepts such as on-orbit repair should also be thoroughly studied since it will be possible to save money and time instead of waiting for the next Shuttle to bring the equipment back to Earth for repair or refurbishment.

(4) We strongly recommend that the crew size at IOC be at least 8 and possibly 12.

Over the past 2 years, the mission plans have consistently shown a larger need for crew time than could possibly be met with just six crewmembers. EVA procedures require two workers outside, and one monitor inside. With a six person crew and 24-hour operations, during EVA there would be nobody to conduct human-tended experiments. Since an EVA will take the better part of a shift (for preparation, outside activity, and unsuiting), there could be many shifts with no ability to conduct crew-intensive experiments.

Several disciplines (space plasma physics, materials science, and life sciences) have repeatedly requested their own specialists aboard the Space Station. These disciplines would have a problem if the Space Station is constrained in size and/or crew. Other disciplines such as astronomy, and physics and chemistry in space have a need to have specially trained customer representatives on the Space Station to conduct their experiments. Recently, it has been suggested that there would be two classes of support crew, dedicated customer representatives that would fly more than one 90-day tour and a group of specialists that would fly probably only once to do a particular set of experiments. Another issue that relates to the crew is the organization of the command structure. There are proposals to have a "commander" for purposes of resolving short-term problems about resource management, operations, systems capability, and of course emergency actions. Another proposal is to establish "watch captains" so that the duty could be rotated during the mission to even out the burden. A possible model would be oceanographic ships that have both an operational crew (pilot and engineers) that is responsible for the safety and operation, and also a science crew that wants to obtain the maximum amount of science data.

The TFSUSS feels that automation and robotics can play a major part in the operation of the Space Station, but that it is too soon to tell exactly what that role is. We believe that automation could be used in many areas to relieve the crew of routine tasks that do not require human decisionmaking. Also, the concept of expert systems that could be used to do initial fault analysis or system control was endorsed.

(5) Efficient science operations requires two-way information transmission to/from the station, the ability of a scientist to operate from a remote Payload Operations Control Centers (POCC), and a data archive and distribution system.

We strongly support the desire for two-way video links, possibly including high bandwidth channel and new techniques for video processing. The concept of a remote science POCC satisfies our desire for "home-delivery and pick-up" of data from and commands to the Space Station. Archival data repositories are needed to merge the selected (variable) ancillary data before transmitting the final data stream to a remote POCC. This implies, of course, that there is a ground network for data transmission to each remote POCC. We agreed that the command system should allow "transparent" commanding whenever possible. Transparent commands are those that do not have to be checked or verified by some central organization prior to being sent to the particular piece of equipment. There will be some commands that must be checked because of interactions with other experiments or systems. We feel that two TDRSS satellites are sufficient for all experiments that are envisioned. With 80 percent coverage of the orbit and onboard data storage, no data would be lost.

(6) There is a need for a small, rapid sample return.

A small, rapid sample return capability, without having to wait up to 90 days for the next Shuttle visit, would definitely enhance the science operations. With the return of about 1 kg of material every few days, it will be possible to lower both the cost of putting sample characterization equipment in the Space Station and the amount of crew time needed for data analysis, thus freeing the crew to do more real-time operations. This capability was strongly supported by life and materials scientists for actual samples, and by astronomers for high-density data return (such as laser optical disks). In addition, it will be possible to do a more thorough sample characterization using ground-based equipment and still influence the conduct of the next experiment.

(7) Adaptive and "quick is beautiful" science should be encouraged.

One of the most important recommendations from the summer study was the concept of adaptive science, that is, taking immediate advantage of the knowledge gained in one experiment to iterate and refine the next experiment. The concept of "quick is beautiful" was also strongly endorsed to cut down on the long lead times necessary even for small experiments. We suggest that some small amount of space and resources be reserved at all times to take advantage of late breaking ideas.

3.4 COMMUNICATIONS AND INFORMATION SYSTEMS

Over the past year, starting with the 1984 TFSUSS summer study report, the CIS Team has been working to define ways in which science users of Space Station can establish functional requirements for the CIS and interact productively with NASA's Space Station designers. The key to success in establishing reliable CIS requirements lies in obtaining a clear understanding of the functional elements that constitute productive space science.

A more fundamental question is, what is the basic character of successful science research? Traditionally, basic research is seen to be adaptive and interactive. With each experimental observation, scientists adapt to new knowledge and modify their initial conceptual ideas, scientific apparatus, and observation techniques. Scientific progress is achieved from this cyclic process. The functionality of any system developed for scientific research is therefore judged by the criteria of whether it promotes this rapid iterative process. Most systems developed for space research (i.e., most free-flyers, Apollo, Shuttle) fail to provide the opportunity to do rapid, iterative science. This does not mean that good science is not done on these missions, but that the time it takes to make significant progress in a space science discipline is much longer than for terrestrial laboratory research.

To address this issue the TFSUSS has coined the term "telescience," which describes the interactive acquisition of new scientific knowledge through remote observations and experiments. Telescience involves using the tools of telecommunications for the purpose of acquiring new scientific information. For remote, and possibly hostile, environments where direct human presence isn't desirable or practical, it defines the initial phase of a development to use of teleoperations and/or telepresence. More important, telescience defines a system engineering methodology for acquiring functional requirements. Telescience mandates a systems engineering team approach where the team is composed of scientists, technologists (including human factors personnel), designers, and developers. High fidelity testbeds employing rapid prototyping users with new telescience technologies and techniques are required to develop functional requirements. To promote efficient user feedback, the testbed must attempt to come as close as possible to reality and identify real users to evaluate the functionality of the system prototypes. For the Space Station, the Shuttle program provides an ideal baseline testbed to examine and acquaint users with advanced information system prototypes. These testbeds should be run in parallel with the full spectrum of ongoing science activities.

On August 12-14, 1985, NASA conducted its first telescience conference at Goddard Space Flight Center. The conference was well attended by scientists representing all disciplines and by NASA Space Station Information System (SSIS) staff. The conference report became the starting point for the CIS Team discussions.

Some especially important recommendations from the conference are worth quoting here.

"Steps should be taken now to develop telescience for the Space Station era. An early start, involving the community of scientific users, is necessary in order to ensure that space systems under development actually meet the needs of advanced scientific investigations, that scientific teams are prepared for the new capabilities and fully involved in their definition, and that essential ground-based supporting systems are defined and built up in an evolutionary fashion.

"We, therefore, recommend that NASA initiate a program of telescience development including intense involvement of the scientific community and incorporating definition studies, pilot science projects, and development of necessary basic computer networking systems.

"These steps are necessary to ensure that newly developing technical capabilities can be exploited for scientific programs in a timely way.

"Futhermore, we recommend that a cognizant office be identified in NASA to coordinate these telescience definition and development activities with ongoing space-system design activities.

With telescience and all of its ramifications as a primary consideration, the CIS Team discussed and reviewed the definition and specification of the SSIS. This dictated that before any discussions could begin, an understanding of the operational modes for each science discipline was needed. For this reason, the discussions and recommendations of the Science Operations Team became the focus for the CIS discussions of the SSIS. The CIS Team concurs with and endorses the recommendations of the Science Operations Team. The remainder of the CIS report will concentrate on various aspects of the SSIS that will impact the successful implementation of the telescience concept.

Space Station Science Information

The historical view of space science information has been data derived from a sensor in the form of digital and/or analog data. A clear distinction must be made between data and information. The transformation from raw bits (data) to scientific knowledge (information) is the key element. The SSIS, to satisfy the needs of the science users, must be designed and engineered such that every aspect of that transformation is included. The analysis and knowledge conversion capabilities are often neglected in the overall system design. This happens not because it is considered unimportant in terms of systems engineering, but because functional requirements and budgetary responsibilities for this part of the system are difficult to identify.

The telescience traid for space research (see Section 4.3) presents a new dimension to the definition of space derived information. The data may be obtained from the sensor observing the science phenomena and/or the operation and control of the experiment. Each form of data can have significant impact on achieving an adaptive and responsive research capability. Scientists, in space and on the ground, must be able to work together as efficiently as if they were conducting research in the same laboratory room. This requires the development of a number of human-scale support tools such as display systems for experimental and simulation results, and audio and video recording and analysis systems. In addition, two-way communication channels between and within the distributed elements must be provided to carry real-time voice, video, and computer-to-computer information flow.

The space science community is only beginning to become aware of the value of voice and video in space research. This lack of practical experience in the use of video and voice in space experiments has resulted in inadequate specification of user requirements for these capabilities. Scientists have little experience to draw from to address engineering design areas such as the number and bandwidth of video and voice communications channels, digital or analog systems, allowable compression techniques, interface standards and protocols, and storage/retrieval architectures. NASA, in the absence of specific new user requirements in this area, assumed that they did not exist and based the SSIS design on Shuttle-type operations and public affairs specifications for video and voice. Accommodations for specific voice and video capabilities for telescience are presently missing. A program to acquaint potential users (both science users and operations users) with new video and voice capabilities presently does not exist.

User Involvement in SSIS Design

All of the major phases of design and execution of space scientific investigations must be reexamined and appropriately restructured to take advantage of emerging telescience capabilities. An important question is, how do you effectively involve users in SSIS design? The traditional approach to requirements definition is to ask a representative group of users to develop those requirements during the early Phase B activities. This approach has severe limitations. It does not recognize the fact that users lack sufficient experience with new technology to specify engineering requirements and that requirements are dynamic and evolving throughout all phases of a project. There is need for a new systems engineering approach to requirements that involves the users in an interactive manner throughout all phases of the Space Station Program. The CIS Team recommends that a consortium of university users be established to provide technical expertise on SSIS architecture and configuration, and to address and study SSIS requirements in terms of science functionality. The testbed and rapid prototyping concept was considered the most efficient and effective means of user-designer-developer interaction. Also, we recommend that existing space science programs (i.e., Shuttle and other space or laboratory projects) should be employed as testbeds as soon as feasible.

In considering user involvement in SSIS design, keep in mind that the individual science discipline communities are international in scope. Testbeds for communications networking, standard interfaces, science information archiving and retrieval, and general experiment operations should involve the appropriate international mix of users. Presently no international user group has been formed to interact with the SSIS designer.

Ada as a Space Station Language

NASA has specified that the Space Station core application software system will be developed under Ada. This action was taken because NASA determined that Ada offered significant advantages in producing reliable and maintainable software. An early decision was made to facilitate studies and early prototyping, to promote its acceptance and usage, and to establish its sufficiency for Space Station applications. The CIS Team concurred on this approach based on the knowledge that Ada provides a good medium upon which to build modern software engineering technologies and methodologies. These same advantages could benefit the science user of Space Station. If this is to occur efficiently, NASA must make a definite effort to provide support to educate science users about Ada. NASA should immediately investigate the use of Ada for Space Station payload applications. This study should also include the ground processing and analysis software system developed for science users.

Automation and Robotics

The CIS Team discussed the implications of a vigorous automation and robotics program on space science research. The telescience concept, by its nature, will require considerable application of automation and robotics. The benefits are clearly evident for such areas as payload engineering, payload timelines, payload integration and testing, payload operations and control, ground and space communications network management, and satellite and payload servicing. Since human resources in space are limited, the introduction of autonomous systems is seen as a valuable and necessary part of Space Station. Relieving the crew from monotonous and routine tasks provides needed time to carry out scientific operations. The user of expert systems as a tool to assist scientists in analyzing and evaluating science information is still considered to be in the future but worth pursuing.

Our evaluation of the newly formulated Automated and Robotics (A&R) Program within the Office of Aeronautics and Space Technology (OAST) and OSS produced disappointment among the panel members. Little or no emphasis was given to applications of A&R to any space science-related need or to payload operation. The program was viewed as an internal NASA program with little or no participation from the university research community. The A&R program, as presented, lacked a specific Space Station goal or direction. The OAST and the OSS efforts were lacking in coordination. Adequate funding was not available to develop the A&R systems for IOC, conduct the basic research and technology development, and train new A&R personnel. The CIS panel recommends that the space science community would be better served if a balanced A&R program involving NASA Centers, universities, and industry was formulated.

NASA's SSIS Organization

The CIS Team spent considerable time addressing the shared responsibility for management and budgetary aspects of the SSIS. The roles and responsibilities for the various offices within NASA (OSTDS - space tracking and data systems, OSSA - space science and applications, OSS - Space Station, and OAST - aeronautics and space technology) are well defined both in a management sense and a budgetary sense. This present NASA organizational structure does not lend itself to a coordinated end-to-end SSIS definition and development. During our discussions, NASA present-ed a color coded chart representing the budgetary and management responsibility of each office for segments of the SSIS. The complex multi-colored chart indicated that no office had lead responsibility for the entire SSIS and that interconnected elements of the SSIS were funded and managed by different offices.

To facilitate a systems engineering approach to the SSIS, the CIS Team recommends that the following urgent issues be addressed. The first and foremost is the appropriate leadership role for OSSA in the SSIS design and development. OSSA must assume the management and budgetary responsibility for the definition of a complete set of science information system requirements. This responsibility will include management of science-related testbeds and requirements studies. OSSA should be properly staffed such that adequate representation and coordination occurs between OSSA, OSS, OSTDS, and OAST. This is beginning to occur, but the process should be accelerated. The information systems and the automation and robotics efforts within OAST must be more responsive to the scientific community's telescience needs. Strong direction for this focus must come from OSSA. The same statement can be made for the relationship between OSTDS and OSSA on communications issues. OSTDS should have responsibility to provide support for not only the traditional space-to-ground elements of the communications systems, but also the distributed space science analysis network on the ground. OSSA has the responsibility to provide to OSTDS a carefully integrated set of telescience communications requirements to meet the needs of Space Station science users. The key to the above recommendations is the assignment of full-time dedicated personnel from each office to SSIS design and development team.

4.0 GENERAL PERSPECTIVES OF SPACE STATION

The discussion of the preceding two chapters focuses on specific issues related to the establishment and growth of a research-oriented Space Station. Equally important, however, is the need to articulate more clearly a basic set of assumptions and expectations to provide general guidelines for the design, development, operation, and future evolution of the Space Station. The TFSUSS recognizes that the Space Station Program is an activity that derives impetus from larger objectives than those of scientific research alone. Nevertheless, much of the current justification for specific functional features of the Space Station is based on an expressed desire by NASA to facilitate the needs of potential users, including scientific research. In these circumstances, it is incumbent upon the scientific community to analyze its desires, present and future, and to argue strongly for those features of Space Station that will best serve them.

The Space Station represents an important departure from previous research activities in space, including even those forays undertaken several times a year with Spacelab. Having permanently manned and operated scientific laboratories in space means that the Space Station will inevitably be compared with other large, national research facilities. These, of course, are subject to considerable scrutiny with respect to their costs and research productivity. Justification for their continued operation is provided by the persuasion of active and informed managers, and the value of the research done by the scientific users.

It is to be expected that the Space Station will undergo similar close investigation during the next decade. To survive and grow under these conditions, the Space Station will require the development of unambiguous support from a large segment of this Nation's scientific community. This, in turn, will occur only if the technical products of Space Station research gain the interest and respect of the scientific constituency and tacit support from the general public.

The TFSUSS feels that in order for the Space Station to be effective as a research facility, it will have to demonstrate two important characteristics: High-caliber technical results of general interest to science, and cost-effective operations.

Through the experience of its members, TFSUSS can provide some advice with respect to the former. The latter lies within the province of NASA.

To become a first-class research facility competitive with other national laboratories, the Space Station must create a scientific environment that encourages rapid technical progress in a variety of disciplines. There are many environmental and transportation factors that make Space Station a unique facility. Nevertheless, even with these difficulties, the pervading philosophy of operation and the goal of the managment infrastructure must be to support research in a way that emulates the successful models of ground-based modern research laboratories.

The following sections provide general discussions of scientific methodology as it is practiced in modern scientific laboratories and, subsequently, identification of key concepts which, if adopted, will facilitate acceptance of Space Station as a successful research facility. From a narrow point of view, the discussion may be regarded as too general to be of practical use: No decisions are required from any one individual, no specific equipment is requested, no time schedules are proposed. Nevertheless, unless there is appreciation of the importance of these ideas, much of the potential for valuable scientific work inherent within the framework of the Space Station will be in jeopardy. Instead of outstanding scientific achievement, the consequence can be erratic, nonproductive technical efforts of little long-term value.

4.1 SPACE STATION AND THE METHODOLOGY OF SCIENCE

The design process for Space Station is underway with the goal of producing facilities that will provide services for a variety of potential users. Both industrial and scientific research users have been identified as having important interests in the facilities. Space Station figures prominently, for example, in the plans of NASA's OSSA and in those of ESA. There can be no doubt that research, and especially federally funded research, will be the primary productive activity early in the operation of the Space Station facilities. Hence, all major facilities and capabilities of the Space Station must be evaluated in terms of the needs of its research users.

With this perspective, NASA and its contractors have begun a design process that involves evaluating the resource and operations requirements of a variety of potential scientific experiments that may be conducted with the Space Station if funds are available. This "bottom-up" engineering design approach attempts to take into account the myriad of factors that enable the facility to meet the projected needs of its users. The TFSUSS has been a part of this design methodology by assisting in the evaluation of potential NASA missions and in assessing the overall quality of the proposed scientific research environment.

However, this approach avoids asking a fundamental, "top-down" question about the Space Station project; namely, what special features or operational characteristics should be incorporated into the Space Station for it to rank as a first-class research facility? In view of the significant resources projected for operation of the Space Station, clear expressions of the scientific goals and tools needed to support high-quality scientific endeavor in Space Station laboratories are clearly in order.

Many important consequences can be seen from a comparison of Space Station with ground-based national research laboratories. For example, it will be increasingly necessary to judge the productivity of space laboratory work on the basis of its scientific impact: The remoteness of space or the difficulty of a measurement in a hostile environment won't be sufficient apology for either poor quality work or the expensive pursuit of unimportant information. From this point of view, the resources spent on Space Station science will be seen within the overall context of the total basic research endeavor of the appropriate scientific disciplines, and achievements must be evaluated within national and international discipline goals. There will be a need to evaluate the Space Station laboratories according to standards that apply to ground-based facilities of comparable operational expense.

With this competitive aspect now expressed, it is useful to summarize the operational techniques of scientific research in successful ground-based laboratories. Conducting experimental scientific research involves scientists working with technicians (and/or students) in laboratories and developing specific experiments to expand knowledge about certain processes. The goal is to obtain new knowledge. Generally speaking, a scientist will provide the intellectual direction for the work. This person, equivalent to NASA's Principal Investigator, will oversee the progress of the experiment and interact with support workers, who have close contact with the specific experiment apparatus and supporting diagnostic facilities, to analyze the results of the investigations.

In most successful research laboratories, the research results are almost always readily available in one form or another, and changes in instruments and/or methods can be initiated quickly in response to the results. Often the resources required for new work are relatively small. Generally, the scientific results of experimental work are obtained rapidly, new ideas can be explored quickly, and new directions of research can be recognized and exploited. It is also important to note that nonproductive experiments occur frequently and are regarded as a normal part of the scientific method: Trial and error is an essential ingredient of research and a fundamental part of the "hypothesis/test" operationalism of the scientific method.

The contrast of the above laboratory environment with that of space is striking. In the early era of unmanned facilities in space, remote instruments operated in a hostile environment, where reliance was placed upon automated collection and transmission of data according to inflexible programs of operation. Resources were scarce and the costs of the experiments were extraordinarily high due to the difficulty of transportation and the complexity of environmental support.

The modern era of unmanned satellites and the tentative steps towards manned laboratory work in Spacelabs are more promising. Telecommunications systems are available, and microprocessors permit flexibility of instrument and experiment operations. Nevertheless, an enormous investment of time and creative energies is required to mount space experiments. Especially for Shuttle-based activities, time in space is short and the wait for the next flight opportunity is long.

A result of these and other factors has been that scientific progress, measured on the scale of ground-based laboratories, is slow. Many years can pass from inception of original ideas to experimental activities. Major discoveries can languish during long waiting periods for new observations or tests. Further, innovation with new experiments is difficult due to a need to avoid the perception of failure and to demonstrate financial responsibility with successful missions. As a consequence, the flexibility and innovation of research conducted in ground-based research facilities have been lost, with an undoubted negative impact upon the quality and creativity of space-based research.

The Space Station has the potential to overcome these difficulties. With the proper organization, facilities, and resources, the TFSUSS can see the possibility that the Space Station laboratories can become an active, vital part of the U.S. and international establishment, competing directly and effectively with other large, user-oriented facilities for its funds and share of recognized scientific achievement. This possibility has excited the TFSUSS and led us to actively support the Space Station project. However, unless certain ideas are adopted in the design and operation of Space Station, these hopes will be unfulfilled, leaving the facility to be judged on the basis of its other, less quantifiable contributions to the space infrastructure.

4.2 SCIENCE IN SPACE AND SPACE SCIENCE

One of the remarkable aspects of Space Station is the extent to which it will facilitate development of "science in space." Up to the present time, the major emphasis of NASA space research has been upon exploiting space for exploring the Earth, Sun, solar system, and the surrounding universe. Most of this work has been done with outward-looking remote sensing instruments, but some has involved in situ equipment and even voyages of discovery where landings and temporary lodgings have been found for scientific experiments and their human companions. Much of this work has been called "space science," with its principal components including astronomy and astrophysics, Earth observations, solar physics, and solar-terrestrial physics.

It is also true, however, that Space Station will allow the conduct of other types of experiments enabled by the low acceleration levels expected (and planned) for the research laboratories. In a sense, this type of research will be inward- rather than outward-directed and, as such, brings activities to Space Station that are in the main stream of ground-based science.

Given these two main preoccupations of research work to be done with Space Station, it seems worthwhile to broaden the nomenclature: A major goal of Space

Station, and especially the manned core, will be to facilitate the conduct of science in space. While the distinction between space science and science in space may seem to be a small point, the TFSUSS is convinced that major consequences will derive from it, including changes in funding of science activities in space (see Section 4.6), the operational structure of the laboratories, and the public's perception of what is happening in these facilities.

4.3 TELESCIENCE

Scientific research conducted in remote, hostile environments is difficult and expensive. Work done in Antarctica and at depth in the oceans provides terrestrial analogs that can be used to guide us as to what can be expected in space. In particular, we note the current singular importance of the trained observer (or Principal Investigator) in remote research. Individuals who possess special training and scientific skills are sent (by ships, aircraft, etc.) to remote locations to conduct their research. Once the background observations have been made and samples collected, among other things, individuals return to their home institutions to analyze and publicize their results. If new observations are needed or new things need to be done, the individuals must either return to the remote environment or depend upon surrogate investigators to continue the work.

It is appropriate to ask if this model of scientific activity is appropriate for the Space Station. In fact, in the early period of the Space Shuttle development, it was thought that investigator visits to space would be a useful mode for conducting space laboratory experiments. Sadly, experience has shown this not to be a viable model. Transportation of humans and equipment to space with the Space Shuttle has proven very expensive, and repeated trips by single individuals are, and will continue to be, a rare occurrence. Thus, the terrestrial models involving the transportation of large numbers of scientists to their work locations seem inappropriate in the foreseeable future of the Space Station.

An alternative is to bring the remote environment to the investigator. By this we mean that while the instruments and experimental facilities are in space, complete information about and control of the remote processes are brought to the investigator at some appropriate location on Earth. The tools of telecommunications can be exploited to emulate the advantages of physical presence at a remote laboratory. This concept of conducting research remotely, using both telecommunications and a variety of other machine-based tools, is termed telescience.

In addition to eliminating effects arising from distance, telescience has another important characteristic: It permits the conduct of "adaptive science," where the immediate results of an experiment can be cognitively evaluated by an investigator, and new experiments or observations can be made rapidly to further test a hypothetical model of the process under investigation. Of course, not all scientific research involves such short time scales for understanding, vis-a-vis implementing new experiments. Nevertheless, the ability to access a remote laboratory in such a manner is a fundamental step forward in conducting scientific research in space (or even in Antarctica or under the oceans).

In its most perfect form, telescience might offer the capability of operating a remote laboratory in absentia: After installation and checkout, no human need be present for a scientist to conduct remotely a wide range of laboratory experiments. Approaches to this type of automation have been seen already in space astronomy. The International Ultraviolet Explorer, for example, permits investigators to control a telescope from Goddard Space Flight Center or from a site in Europe. Data gathered from space can be assessed quickly for its quality, and new commands can be given to improve the observations. In a similar way, the Viking instruments and tools on Mars could be controlled remotely from the Jet Propulsion Laboratory in California. Small trenches dug in the ground near the Viking lander provided important understanding of the nature of the Martian soil and the effects of winds in surface erosion. (It is also notable that no living creatures were seen under rocks moved by remote control!)

While fully automated laboratories may be useful, they are also very expensive and technically difficult to create. Such appears to be the case with the proposed Space Station laboratories devoted to life sciences, as well as the material sciences and applications. The research work done in these disciplines has not been automated on Earth to any great degree. Completely automating a terrestrial laboratory would be a formidable task in its own right. Doing so in space is, in the near term, a practical impossibility, and even modest efforts would entail substantial funding.

In these circumstances, the presence of technically trained laboratory workers in space is essential. However, except in special circumstances, it isn't necessary for these persons to be the equivalent of Principal Investigators. Through telescience, a triad of interaction can be established permitting ground-based research workers, space-based humans, and the supporting equipment to be synergistically linked for the purposes of conducting experiments and/or observations. This relationship is illustrated in Figure 4-1.

From the above description and what has been said in the last chapter, it can be seen that telescience offers a general concept for conducting remote scientific observations. The purpose of telescience is to facilitate the acquisition of new knowledge. Other concepts, such as telepresence or teleoperations, focus on narrow aspects of remote activities and are, consequently, less useful in describing the overall goal of knowledge acquisition. The TFSUSS feels that the concepts of telescience are essential to the success of the science in space projects contemplated for Space Station. They also offer a natural progression of technical competence with respect to telecommunications and machine support tools for remote activities. As these improve and experience is gained in their use, the role of humans in remote research activities will change.

4.4 QUICK IS BEAUTIFUL

Freeman Dyson, in a recent article in Science 85 magazine[1], discussed space research within the context of the expectations of science. One key paragraph expresses ideas that have struck sympathetic chords within the TFSUSS:

> "My main message is that big science is not necessarily good science, that the economies of scale presumed for large space missions are usually false economies, especially if they're bought at the expense of speed. Quick is beautiful. The most important discoveries are those which cannot be planned in advance. If we want to do good science in space, the most important requirement is to have available a wide variety of missions and instruments, so that we can jump quickly to take advantage of unexpected opportunities.

1 Dyson, F., "Space Butterflys and Other Speculations," Science 85, 127-130, 1985.

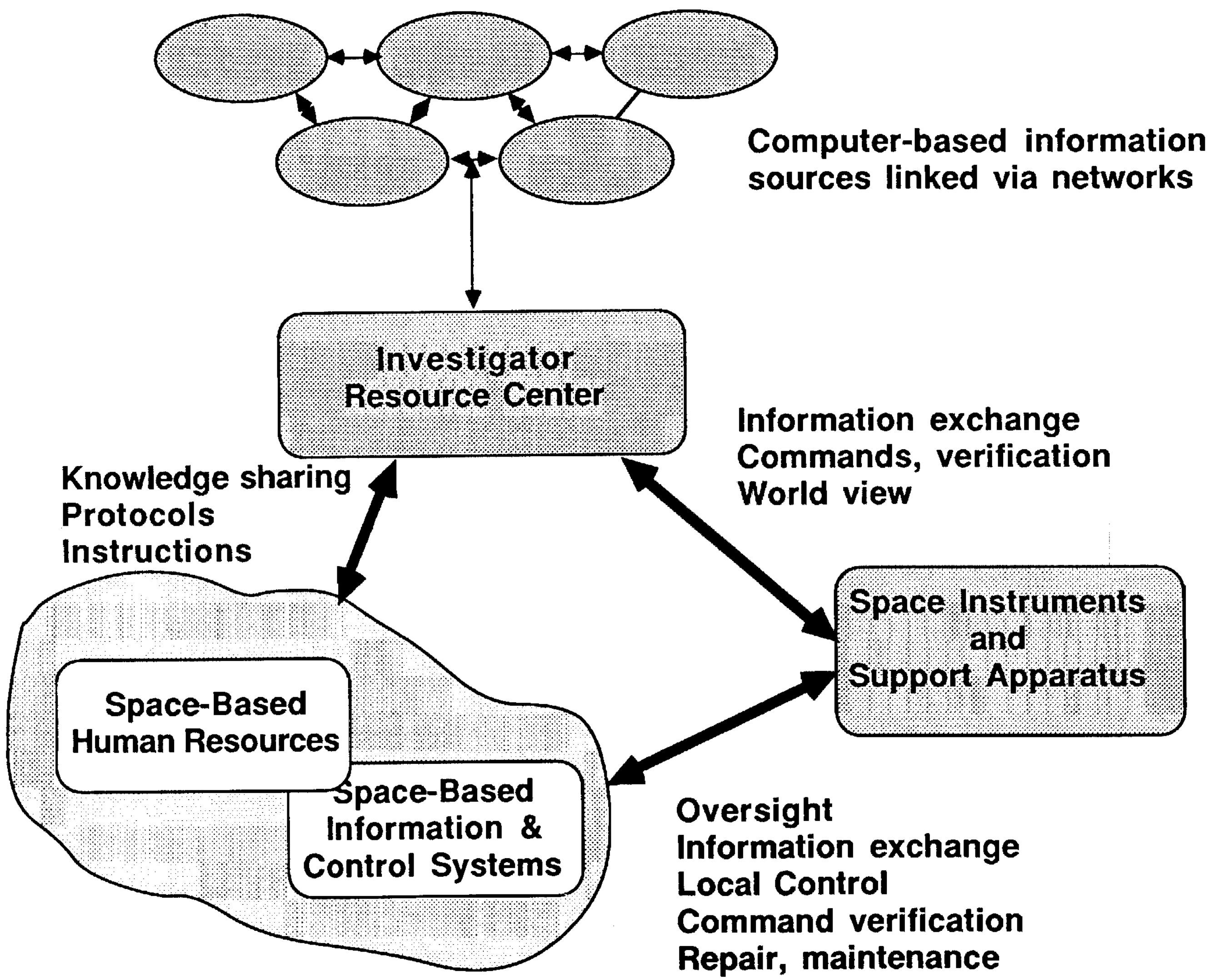

Figure 4-1 Triad Arrangement of Space Telescience

The TFSUSS encourages NASA to adopt policies that foster the development of flexible capabilities and support a wide spectrum of activities. This is related to an operations philosophy that both permits and encourages adaptive research. NASA must allow experiments to use high-quality, industrial-grade hardware without extensive (and expensive) flight qualification. NASA must also permit the maximum possible flexibility in adjusting experimental apparatus and procedures on orbit without extensive ground verification.

One way to encourage development of a broad spectrum of space experiment opportunities is to broaden the authority for experiment selection. Small experiments should involve decisions by appropriate middle-level, science discipline managers without involving the full attention of high-level flight selection committees. The procedures and extensive investigations of the latter should concentrate on big undertakings and major facilities.

4.5 SCIENCE MANAGEMENT FOR SPACE STATION

To date, NASA representatives have said little about the management of research activities on the Space Station. The TFSUSS is very concerned about this situation. Management must work in parallel with physical facilities to produce an effective research institution. The following points have surfaced in discussions on this topic:

(1) The science operations of Space Station should be separated from the operational management of the overall facilities. We believe that the science operations should be set up as one of the "vice presidents" of the overall management structure. The facilities management would be another vice president, and perhaps commercial or "enterprise" activities should be another. To the greatest extent possible, these areas should be independent. Only when some unresolvable conflict occurs at a lower level, such as a resource allocation change or minor contingency problem, should the president be called in to make a decision. This structure implies that all the Space Station functions are responsible to one person or "board of directors." If the system is set up with separate chains of command, we will return to the problems of the Shuttle era where the facility dominates the user.

(2) A Space Station science management infrastructure is needed that would set long-range scientific goals, distribute information about flight opportunities, and evaluate and meritoriously select flight experiments with varying degrees of peer evaluation (major evaluations for large projects; smaller degrees of evaluation for small activities).

(3) A science-oriented operations support activity is also needed, separate from the Space Station operations facility. There is a need for support of preflight experiment development, simulation, and training of the flight crew and investigators. This activity would also assist in organizating support for the flight operations phase of the experiments, perhaps implementing telescience at a central facility or providing equipment to permit the experimenter to conduct the work from a home institution. It is essential that this science support activity have strong ties with the scientific communities using the Space Station facilities.

(4) Specific resources must be allocated to the research activities of the Space Station, and these must be under the immediate control of a science operations manager who controls the daily science operations activity schedule, including the science crew, laboratory energy budget, and communications. Separation of the science activities from the general Space Station support activities avoids having to train the general Space Station manager in all aspects of the laboratory work.

(5) Plans for growth in scientific research facilities and capabilities must be driven by the needs of the scientific users. As with all major national laboratories, experiment user panels or the equivalent must be established to provide the administrative science managers with direct input from the user communities.

(6) The science management structure must include mechanisms for incorporating the participation of scientists from all nations represented in Space Station.

4.6 FUNDING OF SPACE STATION SCIENTIFIC ACTIVITIES

It is important to consider that basic life and physical sciences research in the United States is conducted largely with financial support from the National Science

Foundation (NSF), the National Institutes of Health (NIH), and NASA, with a division of interests drawn somewhat ambiguously along a line separating ground-based from space-based activities. It is likely that the Space Station will break this artificial barrier. As the realization of common interests between ground-based and space-based research grows, NSF and NIH must become involved in supporting fundamental research done in space.

In the long run, the only important distinctions that can be made between the space and ground laboratories are the low acceleration environment within the Space Station and its physical location above the Earth's atmosphere. Countering these benefits will be the obvious difficulties of transportation, communications (relative to ground facilities), physically restrictive facilities, and an intrinsically high operations cost.

An important aspect of this blending of support may be the establishment of ground-based laboratories that provide capabilities parallel to those of the Space Station. These will be needed both for preflight simulations of activities to be done in space, and for the execution of parallel experiments to provide control results.

Finally, it is important to consider that the costs of mounting a new program of scientific research in the Space Station are large. Unless the existing budget of OSSA is increased substantially, there is no practical way of expanding the current OSSA program to include new Space Station activities while maintaining the level of excellence characteristic of NASA's space research programs. Even now, the traditional problem of balancing the costs of facility development and operations with the costs of direct scientific activities is very difficult. What will happen when a new cadre of Space Station science activities and investigators are added to the rolls? Resolving this must be the single, highest priority concern of OSSA if the scientific community's support is to be obtained for the new Space Station activities.

4.7 INTERNATIONAL ASPECTS OF SPACE STATION

Space Station is planned as an international project with important hardware contributions from many nations. The scientific work done in the laboratories developed by this consortium will be equally international. As a consequence, NASA must be prepared to change many of its nationally-oriented selection, funding, and management procedures.

During the past 2 years , the TFSUSS has had close contact with representatives of its parallel organization in ESA (the Space Station Users Panel). Discussions with these individuals indicate agreement on a list of "international" topics that must be explored in the near future. Among these are:

(1) **Selection of Science Projects**. Meritorious, peer-evaluated selection of research projects is essential.

(2) **Resource Allocation**. The allocation of Space Station facilities and resources among nations in proportion to their hardware and operating cost contributions seems unwise in terms of the desire to create an international collaborative facility that supports first-rate scientific work. Exclusive national use of contributed facilities, even for brief periods, would violate the sharing concept implicit in the Space Station plans.

(3) **Science Collaborations**. The TFSUSS believes that international scientific contributions to the Space Station are as important as the initial hardware contributions now being solicited. Agreements and understandings about the nature of this collaboration must be developed in parallel with corresponding understandings about the physical facilities.

(4) **Science Management**. The management of the science program must reflect the international character of the enterprise. OSSA should take a leading role in defining a suitable international science management structure. Likewise, OSS will need to explore models of international operations for the overall facilities.

(5) **Funding**. Methods of funding the Space Station scientific programs may differ radically from what NASA is doing. This should be investigated immediately as part of the science management study.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The second TFSUSS summer study provided a common meeting ground for NASA Space Station planners and representatives of all major scientific disciplines involved in space research. The research participants in this year's study were impressed with the extent to which suggestions made from the scientific community during the course of the past year have been incorporated into NASA plans and the study activities of the Space Station contractors. There appears to be an understanding on both sides of the speed of events and of the need for the scientific community to fully involve itself in helping with the design of the best possible facility in the face of restricted budgets and other practical limitations.

The reports from the TFSUSS discipline and pan-discipline teams have been given in the two previous chapters of this report. Here, we provide brief summaries of the conclusions and recommendations.

5.1 GOALS

The TFSUSS feels that it is essential that the new Space Station facilities be operated with the goal of producing outstanding scientific results. To do this, research projects conducted using the Space Station facilities must be selected and funded on the basis of outstanding scientific merit as determined by general science peer review procedures. The international character of such selections should be an integral part of the overall science implementation plan.

The Space Station must create and support a research environment that facilitates the development of new ideas and capabilities, especially with respect to disciplines that have not participated extensively in previous space programs.

It is essential that the time delay between the decision to fund and conduct deserving experiments on the Space Station be reduced significantly. Challenging, but reasonable goals are less than 2 years for new, hardware-oriented projects, and to less than 1 year for projects involving the use of existing on-orbit equipment.

The mode of scientific endeavor on Space Station must emulate the adaptive science methodology used in terrestrial research laboratories. Trial and error as part of the scientific method must be recognized and supported by the Space Station science management structure.

Scientific research with Space Station will place heavy demands on NASA and other participating governments to provide adequate management and experiment support facilities. The latter will need to include experiment development areas, laboratories for control experiments, communications to the remote facilities, computers, software support libraries, graphic display devices, and all of the other resources needed to mount and support a vigorous, new program of scientific research in space.

5.2 SPACE STATION LABORATORIES

There is a need for well-equipped, permanently manned laboratories that can support a broad range of fundamental research in space. Experiments within these laboratories will use both facility-class equipment and apparatus provided by Principal Investigators. It is important that, to the greatest extent possible, this equipment be permitted to meet the same construction, safety, and operational standards that apply to equipment in conventional terrestrial research laboratories.

To support the ongoing research program in space, it is essential that telescience be incorporated into the Space Station laboratories. The best possible two-way communications technology must be available as a common resource to link the space- and ground-based experimental apparatus, in-space human support staff, and the ground-based principal investigators as a normal part of Space Station science operations. Access to and use of these communications facilities must be regarded as a normal part of the daily research activities.

The TFSUSS has argued that the largest possible modules should be put in service at IOC, even if the initial demands for scientific volume do not fill that space. Such a plan will avoid the "zero sum" problem of having to remove equipment and apparatus each time a new experiment or important innovation is needed in space. Initial underutilization of available space is especially important in the face of uncertainties about the actual scientific hardware and experiments for the IOC Station.

After considerable investigation, the TFSUSS is convinced that the laboratory gaseous atmosphere must reflect as closely as possible the pressure and composition of the terrestrial sea-level atmosphere. To do otherwise would have great negative consequences for both the use of standard scientific instrumentation and the applicability of scientific results obtained on Earth, especially with respect to life sciences.

To facilitate science projects and to keep science costs lower than might otherwise be the case, it is highly desirable to permit the use of standard laboratory equipment. Onboard storage space should be provided for standby laboratory hardware, which would enable rapid onsite experiments in support of general scientific activities.

The question of crew safety arose often during the summer study. There is a feeling that current Space Shuttle safety standards place excessively stringent restrictions on the design, performance, and reliability of space apparatus and upon the crew activities. In the more commodious environment of the Space Station, such standards may prove to be excessive. Efforts must be made to arrive at standards that protect the facilities and crew, while recognizing the potential safety issues that apply to any modern electrical or materials research laboratory. Considerable experience has been gained in such matters in other isolated environments (such as submarines and polar research stations), and NASA is urged to review its applicable safety standards to achieve a reasonable state of personal and systems security. Participation of Space Station science users in such a safety study would be most appropriate.

The size of the science support crew is crucial to the orderly accomplishment of the science schedule and the overall scientific productivity of the facilities. While a total Space Station crew size of six persons appears to be adequate to demonstrate future capabilities, the TFSUSS recommends a crew size of 10 persons to permit both Space Station operations (2 persons) and science and other operations with ongoing maintenance and repair (8 persons). It is also clear that an important goal of the scientific work to be done in the manned laboratories will be investigations related to human and animal physiology. Reduction of the science crew to fewer than eight persons will place such programs in jeopardy in terms of having sufficient staff to conduct and monitor the necessary research work.

Achieving low steady-state acceleration levels on Space Station is important for a wide class of materials science and physics and chemistry experiments, both at IOC and in the years that follow. We recommend that a target goal of 10^{-6} g be used and that the laboratory modules be clustered along the flight path of the center of mass of Space Station. Furthermore, time-dependent accelerations must also be minimized, which will require vibration isolation schemes at the rack level and possibly at higher structural levels. The Space Station can also be used to conduct experiments requiring acceleration levels in the range of 10^{-7} to 10^{-8} g by using an evacuated container as an orbiting "drop tower," in which experiments would follow the geodesic path of a free-floating object in orbit. The possibility of including such a capability, along with other post-IOC scenarios, should be studied closely now so that the implications for the IOC design can be more fully understood.

There is an important need to quickly send experiment samples from the Space Station to terrestrial laboratories possessing sophisticated equipment for sample characterization studies. A "space mail" system capable of delivering small samples of perishable and fragile materials to ground laboratories within 18 hours of experiment termination addresses this need. Availability of this service will have an important impact on the requirements for diagnostic instruments for the Space Station laboratories. We urge NASA to investigate the options for rapid sample return as soon as possible.

If development of the Space Station is restricted by financial exigencies, serious consideration should be given to the lab/hab module concept. By combining laboratory space with habitation support, single modules can help support the smaller crew during the development phase prior to IOC. It is recognized that lab/hab will limit materials and life sciences experiments.

5.3 ATTACHED PAYLOADS

Attached payloads are an important part of the core Space Station. They can make unique use of onboard scientific personnel and serve a number of important functions, enabling observations of the Earth, Sun, other solar system bodies, and astronomical objects. The attached payloads will also serve as sites for testing new and advanced equipment, and as important sites for plasma physics experiments in space, making use of the natural plasma environment surrounding the Space Station. In addition, there are indications from abroad that the materials science discipline will make extensive use of attached payload capabilities. The Europeans and Japanese are already including this possibility in their Space Station plans.

NASA's current plans for Space Station science utilization give low priority to attached payloads. The TFSUSS is greatly concerned about this and urges OSSA to develop a more productive plan which takes into account the important opportunities available with attached experiments. It is estimated, for example, that OSSA will have invested $1-2 billion in Spacelab instruments capable of being converted to attached payload use. These instruments could represent a singular opportunity for NASA to obtain important Space Station scientific results at relatively low cost.

5.4 SPACE STATION PLATFORMS

Free-flying platforms are essential for conducting many important scientific endeavors contemplated for the Space Station era. The TFSUSS is encouraged by the Space Station Program decision to study a modular platform concept as an alternative to a large monolithic platform. The modular concept was enthusiastically endorsed by the Platform Team during the summer study.

The concept of a low-inclination orbit platform at IOC has been considered by both NASA and the TFSUSS for scientific investigations in the areas of astronomical and planetary observations. The Solar-Terrestrial Processes Team has recommended that NASA utilize platforms for active plasma experiments. It is possible that future materials research will require an experiment platform having a lower acceleration environment than can reasonably be obtained in the core laboratories. In this case, a suitable remote platform may be appropriate.

The concept of multi-instrument platforms in polar orbit has received strong support from scientific disciplines involved in Earth observations and solar-terrestrial processes. The platforms are also regarded by NASA as being a keystone of its Earth Observing System, an international undertaking aimed at gathering important information about the behavior of the physical and biological processes on our planet, viewed as a large, interacting association of structured systems.

Polar platforms are also ideal sites for observations of naturally occurring space plasma phenomena representing processes found throughout the solar system and universe. The opportunity to place sophisticated instruments in polar orbit opens the way to a number of important observations of these natural phenomena, and also provides a means of conducting active experiments with the plasma itself.

Evaluation of particular details of platform orbits and tentative payloads must take into account the need for a variety of conditions required by the users. Based on the stated needs of the scientific community, it seems apparent that several polar platforms will be needed to meet user needs with respect to the number of instruments and the desire to have sun-synchronous orbits at different equatorial crossing times. In addition, the solar-terrestrial community has stated that their preference would be for an orbit other than sun-synchronous in order to view natural high-latitude phenomena at various local times.

Another important factor in the use of the polar platforms is NOAA's desire to base many of its operational sensors on the polar platform. This provides both an opportunity for enhancing the collaborative aspects of Earth sensing, and a potential disadvantage if these instruments fail to meet the needs of the scientific community or if the combination of research and operational instruments leads to administrative difficulties.

A concern has arisen with respect to the servicing of polar platforms, which depends on the availability of polar flights of the Space Shuttle. The schedule for these is not well known, but it appears unlikely that such trips will be frequent. This circumstance greatly limits the opportunities for platform and instrument servicing and repair, a feature that is potentially valuable to NASA's planned instruments. This circumstance also represents a difficulty for the operational instruments proposed by NOAA. In the event of a major NOAA instrument failure, for example, what steps will be taken to provide supplemental coverage or extra flights to repair or replace the malfunctioning equipment?

Discussions with traditional space science communities indicate that there is also an important need for small platforms, perhaps upgraded versions of ESA's Eureca and/or NASA's Spartan systems. These subplatforms provide, in principle, for innovation and rapid implementation of small-scale experiments and observations. They are the free-flyer "quick is beautiful" opportunity.

5.5 SPACE STATION SCIENCE IN THE PRE- AND TRANS-IOC PERIODS

The TFSUSS recommends strongly that steps be taken to enhance manned research activities in the pre-IOC period using Spacelabs and other attached payloads on the Space Shuttle. This recommendation was presented to NASA by TFSUSS as a major conclusion of its first summer study. Little has happened in the planning for such an enhanced program in the past year, and the TFSUSS is compelled again to point out the urgent need for experience in conducting manned science research programs in space prior to initiation of Space Station activities.

The TFSUSS has also given its strong support for the development of a low-cost, enhanced duration capability for the Space Shuttle. Extending on-orbit time from the current 7 to 10 days to 16 days would have an important, positive impact on the scientific productivity of currently planned science missions and, more importantly, would provide the opportunity for obtaining the urgently needed experience in space needed for the support of manned research activities.

It is also possible to use the pre-IOC period as a time for testing new concepts in space-ground coordination of experimental work. Substantial improvements are possible in the organization of experiment communications, and attempts should be made to explore the different parts of the telescience idea, including extensive use of two-way video communications, the use of small onboard interactive computers, and communications to investigator home institutions.

The trans-IOC period is a transition phase that starts with the first assembly of Space Station structures on-orbit and ends when the facilities have reached the point where science and station operations can be regarded as two separate activities. Although planning of this development period is still underway, it is important to investigate the ways that some science can be undertaken in parallel with the assembly efforts. In particular, periods may occur when the partially constructed Space Station is unmanned or, in contrast, when human resources are available to conduct research projects.

The concept of a man-tended mode of scientific activity aboard the Space Station presents the possibility of using on-orbit laboratory modules during periodic forays to space. The TFSUSS considered the implications of such activities in the light of the needs and plans of its disciplines and found that such a development was of little value except to the extent that it would support somewhat longer experiment times than were available with the Space Shuttle. The essential need was for a truly long-term, manned capability.

While the trans-IOC, man-tended mode of operation would place substantial restrictions on the program of man-assisted research, such a state of affairs would clearly be better than having no research capabilities at all. It is possible that some experiments could be automated to permit operations in the absence of the scientific crew. However, the spectrum of experiments that could be undertaken in this mode is greatly restricted owing to practical considerations of safety, sample characterization, and the intrinsic costs of developing such capabilities when little practical experience along these lines has occurred in ground-based laboratories. It is also clear that research related to animal and human physiology would be restricted to the relatively brief periods when humans would be in space.

Attached payloads can be an important part of an interim man-tended mode of operation. Much of the equipment developed for external use on the Space Shuttle could, with appropriate modification, become Space Station attached payloads that would be remotely operated by the investigators during the absence of onboard scientific personnel. Such remote operations have been envisaged as an important aspect of telescience, and there is no question as to their importance to the disciplines involved. However, even in this case, certain support features would have to be present to compensate for the absence of support from the space-based crew.

With respect to the development and flight of co-orbiting platforms, delays in the development of the core station should not be allowed to retard their design and flight. Many of the support functions expected from the core station for these platforms can be accomplished using periodic flights of the Space Shuttle.

The same is also true for the polar platforms. To a large extent, the development of this new capability depends on support from the Space Shuttle and, if the trans-IOC period is protracted, thought should be given to launching and operating these important facilities in the absence of the manned core.

5.6 SPACE STATION SCIENCE IN THE POST-IOC PERIOD

Even at this early stage of planning for Space Station, it is essential that NASA look ahead to the activities that are anticipated over the 25- to 30-year lifespan of the core facility and its associated elements. From a scientific viewpoint, advances come from the extension of operations at various physical limits (such as g-level, angular resolution, and contamination levels) which constrain experiments. Thus, in order for the Space Station to be useful for future scientific endeavors, it must adapt to the needs of its scientific clientele by incorporating design features that permit evolution of the facilities at reasonable cost. The TFSUSS is very concerned about the general lack of long-term scientific planning for Space Station and the implication this has in terms of the architectural plans now under development. The TFSUSS recommends that OSSA undertake studies of advanced experiment, which may impose special demands upon the design of the Space Station.

Furthermore, future Space Station planning should consider the appearance of deferred items: the need for additional modules, the growth in resource requirements, and the accommodation of new types of facilities, such as free-flying drop towers and tethers. Options for growth, such as replication of existing structures as well as growth of components on existing structures, must be carefully investigated.

The TFSUSS foresees that additional activities, such as advanced technology development, will also require use of the Space Station as a testbed facility. Areas such as supporting future planetary missions and geostationary platforms should be included as elements of planning in the post-IOC Space Station. The TFSUSS feels that NASA should identify these areas in more detail and include additional future requirements as part of the architectural design process.

Finally, throughout the post-IOC planning process, the intrinsic growth limits must be defined carefully in terms of the supporting transportation and communication systems. The limits set by STS delivery of equipment and personnel to the core station, the lack of frequent access to polar orbiting platforms, the limitations of the TDRSS communication system, and other such problems will act in concert to set boundaries of reasonable growth.

APPENDIX A

LIST OF SUMMER STUDY PARTICIPANTS
STANFORD UNIVERSITY, STANFORD, CALIFORNIA
AUGUST 19-23, 1985

TASK FORCE

Peter M. Banks, Chairman	Stanford University
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Joseph V. Brady	Johns Hopkins University
John Carruthers	Intel
C. Richard Chappell	Marshall Space Flight Center
V. Reggie Edgerton	University of California at Los Angeles
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David A. Landgrebe	Purdue University
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John Logsdon	George Washington University
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John P. Wefel	Louisiana State University
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NASA PERSONNEL

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Roger D. Arno	Ames Research Center

Rodney Ballard	Ames Research Center
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APPENDIX B

SPACE STATION TASK FORCE SUMMER STUDY

August 19-23, 1985

AGENDA

<u>Monday, August 19th</u>

8:15 a.m.	Registration
8:30	General Welcome
8:45	Task Force Activities Update (Banks)
9:30	Team Activities at Summer Study (Team Leaders)
10:30	Science Planning for Space State Era (Rosendhal/Sade)
1:00 p.m.	Discipline Team Meetings
3:15	Pan-Discipline Team Meetings
5:00	Adjourn
5:30	Reception at Faculty Club

<u>Tuesday, August 20th</u>

8:30 a.m.	Space Station Overview, Trade Studies, Utilization Information Systems, Operations (Hodge, Craig, Raney, and Hall)
1:00 p.m.	Discipline Team Meetings
3:15	Pan-Discipline Team Meetings
5:00	Adjourn
8:00	International Forum

<u>Wednesday, August 21st</u>

8:30 a.m.	General Discussion: Small, Adaptive Science
10:30	Discipline Teams
2:30 p.m.	Pan-Discipline Teams
5:00	Adjourn

Thursday, August 22nd

8:30 a.m.	General Discussion: Science Operations
10:30	Discipline Teams
2:30 p.m.	General Discussion: Configuration and Evolution
4:00	Pan-Discipline Teams
5:00	Adjourn
8:00	Using AI for Automating Science (Buchanan)

Friday, August 23rd

8:30 a.m.	Team Meetings
1:00 p.m.	Team Presentations
5:00	Adjourn